AN URBAN AREA USE MODEL TO MAXIMIZE RETURN

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BY

W. DON STEWART

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Research Report

AN URBAN AREA USE MODEL TO MAXIMIZE RETURN

To: Dr. J. F. McLaughlin, Director
Joing Highway Research Project

February 14, 1969

File: 3-8-1

From: H. L. Michael, Associate Director
Joint Highway Research Project

Project: C-36-70A

The attached research report "An Urban Area Use Model to Maximize Return" by W. Don Stewart, Graduate Instructor on our staff is the Final Report on this research project. The project was approved on September 20, 1966, under the title "A Land Use Model to Minimize Transportation" and was conducted from funds of the JHRP. Mr. Stewart also used the research and report for his thesis for the Ph.D. degree. Professor W. L. Grecco directed the study.

The research report includes the development of an urban area use model to maximize net community return. A heuristic procedure for finding a good solution is developed and using simplified data and developed computer programs was tested on the Lafayette, Indiana, area. This test indicated the programs to be operationally practical and economical.

The report is presented to the Board for the record as completion of this research and as information to be utilized in urban transportation planning studies.

Respectfully submitted,

Harold L. Michael

Harold L. Michael
Associate Director

HLM:rg

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Final Report

AN URBAN AREA USE MODEL TO MAXIMIZE RETURN

by

W. Don Stewart
Graduate Instructor in Research

Joint Highway Research Project
Project: C-36-70A
File: 3-8-1

Purdue University
Lafayette, Indiana
February 14, 1969

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ABSTRACT

Stewart, W. Don, Ph. D., Purdue University, January, 1969. An Urban Area Use Model to Maximize Return. Major Professor: Dr. William L. Grecco.

This dissertation reports the development of an urban area use model. The model's normative solution is to be utilized in the allocation of uses to locations so that net community return is maximized. A heuristic procedure for finding a good solution has been developed and programmed for the computer. As a test, the computer program was applied to simplified data on the Lafayette Indiana Plan Area.

From the review and synthesis of principles of land use development and utilizing cost data from the land use and transportation literature, it was concluded that the objective of allocation of area uses is to maximize the gross utility return from the use of area and from economies of scale, less the utility costs of transportation, of adaptation of locations to uses, and of incompatibility between proximate uses.

In order to provide a computationally practical means of obtaining a near optimal solution to the model norm, an iterative solution procedure was devised. For this procedure, an initial feasible solution, such as an existing plan, must be available. From the existing solution the change in net return, as a result of a unit change in the allocation of each use to each location is evaluated, and a number of the more beneficial interchanges are made to obtain a better solution. The maximum

permissible changes in each use per location are then decreased by one-half of their current values. If the new limits are greater than preset minima and if further significant increases in return may be expected, the cycle is repeated.

Gross model data for the Lafayette Indiana Plan Area were compiled from readily available sources, and computer programs developed for the desired solution. The programs were given preliminary testing on this data and were shown to be operationally practical and economical. A study of the speed of convergence towards the optimum was not made.

INTRODUCTION

The history of the culture of man is a story of utilization of his environment to satisfy his objectives. This utilization may take the form of response to the environment or an attempt to manipulate it. In preliterate times, the manipulation was the result of decisions by a single, or at most a few, behavioral units. In early cities such as those of the Greeks, the interactions of the behavioral units within the city raised the need for co-ordination in the form of government. Still, each citizen participated directly in the city affairs. Today the modern urban area is composed of more diverse groups, and is many times larger than the Greek cities. No longer can the agora be built so that each man may speak and be heard by all the citizens. To accomodate the increase in numbers, government is by representatives. Because of the complexity of the urban area, its size, and diverse interests, government is divided into; the setting of policy by elected representatives, formulation of technical guidelines by the planning staff, and application by the executive.

At present, government planners usually act as advisors to the legislative or executive branches of government. The planner is part of the link between government administration and the people of the community, or at least the higher levels of the community power structure. With the advent of this system, individual choice has taken on a lesser weight relative to the welfare of the total community as expressed in the

amalgamation of these choices. Arrow (1951) divides the individual social choices which form the "amalgamation" into two complementary processes; voting and the market mechanism. The former is political and the latter economic. However, voting tends to be a communal decision whereas the market mechanism tends to be more individualistic in its reaction to each input. Increasingly, economics are coming under political control, particularly in the area of land use. Zoning, taxation on real estate, urban renewal, and policy on provision of utilities and streets are examples of government decisions which are intended to modify the market mechanism control of land use. As a result of the increasing role of government, planners must be able to interpret community goals as outlined by legislators and/or the public, and prepare and recommend plans which reconcile conflicts between the goals, within the limitations of the community's ability to satisfy them.

The problem facing the planner is to determine:

1. What are acceptable community goals?
2. What are the relative utilities of achievement of these goals?
3. What are the resource requirements of the activities which are necessary to attain these goals?
4. How would these goals or their requisite activities interact?
5. How is a temporal and spatial combination of activities determined which will optimize return?
6. What controls are desirable for orienting area use locational and growth forces towards achievement of this combination?

In present land use planning, most work is directed at programming public services and expenditures to achieve given objectives or to provide for expected community growth. But there is a trend towards

provision of land use controls to modify community evolution. Thus the planner must rely on judgement to foresee the effect of these controls, or preferably, use a simulation model or mathematical programming to determine the best plan and the necessary controls for its achievement.

Purpose and Scope

This research is oriented towards providing a normative programming model which will determine an allocation of land or area use that maximizes net community return. Thus it is assumed that community goals, their return, and their costs, are known. It is hoped that suitable area use controls, required to implement this allocation, could be formulated from the resulting program. The temporal aspect of planning is not considered, insofar as the programming is for the static case only, whether past, present, or future. It is expected that in a practical application a horizon year would be programmed, and revisions made periodically.

By using the proposed model in combination with Schimpeler's (1967) work on defining and evaluating community goals, a basis for normative land use planning may be achieved.

In the following chapter, the evolution, function, and activities of an urban structure are examined in terms of their interactions, requirements, and fulfillment of community goals. In Chapter III, a model and a norm for area use allocation are developed. In Chapter IV, a heuristic solution procedure is proposed and preliminary tests carried out on gross data for the Lafayette, Indiana plan area. Chapter V contains a discussion of the results, while Chapters VI and VII draw conclusions about the model and make recommendations for extensions thereto, respectively.

URBAN AREA USE ALLOCATION FACTORS

Before defining the problem of optimizing urban structure, it is instructive to consider the urban phenomenon in terms of its development, its individual components, the interactions, and its purposes. Accordingly, this chapter reviews the evolution of cities and the concomitant changes in functional specialization. Then the activities and communications are examined individually and in terms of their form and structure in both the region and city community.

Urban Evolution

The history of land use predates man. Ethologists currently are studying what is perhaps the most fundamental of the behavioral forces, territory (Ardrey, 1966) or land use. The drive to possess and defend territory by individuals or by groups is basic to the most elemental of creatures. Specialization of use of such territory or land is not restricted to man. Such widely differentiated creatures as the sage grouse of North America's semi-arid central plains, and Uganda kobs both have a separate area set aside for procreation, and this function is initiated by specialized males at these areas. In both cases, the location of this specialized non-residential land use is static for a given interbreeding population. An example of an animal which even constructs its own transportation system is the beaver.

Ardrey (1966) presented strong evidence to support the hypothesis

that man is a territorial animal. At one time, the territory was the hunting grounds of a band or tribe. Today there is a hierarchy of territorial use, with the individual exerting full rights over a smaller piece of territory and lesser rights in common with others at various political levels over public territory.

Gras (1922) divided urban development into five stages. The first stage, a collectional economy, was principally that of the hunting bands. Within their territory or region, one or more semi-permanent residential areas were established. One of the main criteria in establishing the territory size and the seasonal residential locations was a feasible range for collection of food, in short, transport. Such cultures, with some cross-cultural adaptations, still exist even in the United States of today (Salisbury, 1962), but most have advanced far beyond this.

Until the start of the second stage, the cultural nomadic economy, man had primarily adapted to his environment. But with the advent of agriculture and domestication of animals, he began to exert some dominance. This initial control of habitat was the beginning of today's modern city, a habitat in which man is almost totally dominant, except over viruses and insects.

The third stage of urban development, the settled village economy, was possible only with development of agriculture as the principal mode of food production. A surplus of food which permitted some separation of function from the farm to the village also provided one of the necessary conditions for sizeable urban areas. The village served as an organization for barter, and thus began to achieve some dominance over the farms.

In the fourth stage, the town economy, inter-area trade began to develop, and the crafts were firmly established as separate economic

functions. This stage required both technological change producing increased agricultural surplus, and new social organization (Davis, 1955). However, the development of trade was predicated on a more efficient transport system. It was probably at this point that the informal village mores began to give way to formal rule of law, and the organization of the community became increasingly complex because of size and extramural as well as internal communication.

At the present time, urban areas have developed to the metropolitan stage. The increased separation of functions within areas, specialization of area functions, and increased and improved organization and transport have produced the metropolitan community. Such a community has a dominant city as the nucleus for an interdependent hinterland area. Gras (1922) described the requirements of the dominant city or metropolis as; development of the market, development of industry, organization of transport and other forms of communication, and development of finance. This analysis was concerned, however, only with the requisite economic functions.

Sjoberg (1955) used an historical classification which is useful for understanding city development, namely; preindustrial, transitional, and industrial. He found that the rigid class system of the preindustrial city had to be destroyed in order to make industry efficient. The physical effects of industrialization, however, were more evident than these social ones. The technology of industry, health and sanitation measures, and improved agriculture and transport produced the ability to build increasing population concentrations (Quinn, 1955). This led to economies of scale, permitted external economies, and tended to minimize the friction of space (Hauser, 1965). Perhaps one of the most striking changes brought by industrialization was the growth of non-residential

land uses, and the separation of residence and place of work.

In an "overview" of this urban evolution, Hauser (1965, p.16) states, "land use patterns and infrastructure development were largely the product of market forces, which produced a remarkable physical plant but which also permitted rapid obsolescence". So long as individual actions had a limited effect on others there seemed to be little reason to restrict the market mechanism. However, as Lampard (1955) notes, "the increasing specialization of functions, which marks an industrializing economy, imposes a greater measure of interdependence among the differentiated parts". Also, the market forces, which shaped many of our urban areas, did not account adequately for social factors due to the market's suboptimization with respect to community goals. As interdependence increased, so social and economic suboptimization increased. Further, the external effects, some of which lead to Hauser's "obsolescence and decay", tended to increase. A current example of public concern with external effects is the movement to reduce air and water pollution. An example of public concern over suboptimization by the market is the support for urban renewal. As Baumol (1962) stresses, the public has a poor idea of optimality since it has little idea of costs. The net result is that problems often have become extreme before they were investigated, and then they were remedied with too little concern for their external effects and interdependence with other problems and activities. Coordination of government action by planning agencies recently has reduced the economic and social waste to some extent. But the planner is hampered by lack of analytical tools for assessing the relative values of diverse and often conflicting goals, and for designing the plan which will maximize

the satisfaction of these goals. It is with the latter problem that this research is concerned.

Distribution and Hierarchy of Cities

In order to understand urban structure, we must consider the entire symbiotic community formed by urbanization. As shown above, interdependence of men has developed over ever-increasing areal extent. For some functions this interdependence is world wide, but for many activities it is within the metropolitan community. The metropolitan community is examined with a brief review of the external effects of more widespread interdependence.

The dominant city and other urban nuclei of a metropolitan community form a hierarchy in terms of both dominance and geographical distribution. Quinn (1955, p.34) concluded that "for each city there is presumably a location that permits maximum ease of human adjustment (to the environment)". There are many factors which apparently can pervert this locational tendency, but it must be remembered that even though the geographical distribution of cities is not optimal for today's conditions, it may be optimal as an evolutionary system. Some of the factors which Quinn noted as opposing efficiency of location are ignorance and miscalculation, taxation, zoning, restrictive legislation, and variations of personal utility. Losch (1954) hypothesized that even on an undifferentiated plane, town location is a function of distance, mass production, and competition. It is instructive to note that distance, mass production, and competition could be restated as transport, technology and trade - the principal economic factors in the evolutionary origin and development of urban areas.

In the real case, Quinn (1955) considered city location to be due primarily to one of the following:

1. Change of transport mode.
2. Transportation route convergence.
3. Power availability.
4. Other natural resources.

The last factor often is broken down to separate the collectional resources such as agriculture and timber, from the localized resources such as mineral deposits.

After an urban settlement is established, a new set of forces determines growth. Berry and Garrison (1958b), speaking on the relative importance of locational and growth factors, note that we attempt, through the market, to balance diversification forces which tend to locate industry near raw materials, with unification forces which tend to locate industry near the market. Obviously, the latter can be effective only after some other force has located a market population in one area. Some raw material-oriented industries may tend to locate near power rather than other natural resources, whereas another industry may do the reverse. The deciding factor likely will be the relative needs for each resource, and the cost of transporting them. But if the costs of transporting power and other raw materials decrease sufficiently, then the industry may relocate near the market. Bogue (1950) stated that the metropolitan community structure is conditioned by the distribution of natural resources even though it is expressive of human organization. Despite this conditioning, current transportation technology is the key factor in determining the community structure.

One of the most striking characteristics of urban areas is their

size distribution. The combination of the size and geographical distribution noted above have led to theories of regional hierarchies of cities, and finally to Bogue's (1950) metropolitan community. Christaller (1933) stated the hierarchical model concept that each central place is an element of one or another of class subsets. Each class executes specific groups of functions and is characterized by a discrete population level of its centers. Bogue (1950) emphasized the existence of metropolitan dominance. He proved that the central city of a metropolitan community (often termed a region) has dominance over that community. Using a bio-ecological approach, he categorized urban centers within the community as dominant, sub-dominant, influent, and sub-influent, in decreasing order of size. Bogue (1950, p.9) summarized this ecological view of cities as follows:

1. The human community (including city communities) is an organization one purpose of which is adaptation to the environment.

2. New techniques of transportation and production (technological change) have permitted great cities to dominate smaller cities and other communities surrounding them.

3. These outlying communities are subordinate to the metropolis and are integrated with it.

4. This integration of outlying territory (hinterland) with the metropolis has become a standard form of social organization throughout the entire United States.

Bogue went on to study the hinterland of a metropolitan community in terms of accessibility, distance, and direction from the dominant central city. He found that dominance varies with metropolis population size, size of subdominant hinterland city (ies), distance from the metropolis, and the type of sector. In general, population density tended to decrease with distance from the central city, but the directional sector was important because of the effect of subdominant centers, transport routes to other metropolises, and resource distribution. This study represented a

model of a process. It is possible that the model could have been extended to cover the entire earth using the same basic concept of levels of dominance. One weakness of the model, however, is that it obscures the overlapping nature of dominance. Bogue notes that metropolitan community boundaries are different for various functions. In addition, it may be stated that these boundaries vary over time and also are the product of a stochastic process of choice, which leads to an indefinite boundary even for a specific function.

In addition to the concentration of population within central places on a hierarchical basis, there is a concentration of central places on a national and even an international scale. Ullman (1958) found that in the United States industrial belt, 7 percent of the land holds 43 percent of the country's population and 70 percent of its industry, and it receives 52 percent of its income. This concentration is a self-generating productive process in which complementary activities pyramid. It is a growth rather than a locational phenomenon which occurs because services and industries that require a large accessible market can grow only where population exists. Since the eastern seaboard was settled first and had raw materials, it began to produce new services and goods, and these in turn produced more. Duncan et al. (1960) concluded that the hierarchy for manufacturing is in fact national, whereas for services it is regional. Alonso (1964), as a result of analyzing industrial location, suggested that locational factors are transport, labor pool, power, materials, and amenities. Many of these factors have least cost in the developed areas, and thus Ullman's pyramiding occurs. However, Alonso noted that many industries are becoming "foot-loose" because of the freedom provided by improved transportation. Amenities in the expanding economy are becoming increasingly important and can favor development elsewhere. Factors

favoring other locations are markets protected by isolation, labor force protected by isolation, local ingenuity, and corner locations which may be favorable to international trade.

Functional Separation, Specialization, and Differentiation

The evolution of our modern metropolis has produced an opportunity for planning to reduce suboptimization. In order to do this, all significant factors should be considered simultaneously else the resultant plan may be inferior to the unplanned development guided by the market mechanism.

The first and most important factor which the planner must consider is the set of needed activities and their position in the urban hierarchy. If planning is being executed for the optimal size city, then each activity accomodated must have a net benefit to the city. Usually, however, the city size is not controlled, and types of activities allowed are controlled only by criminal law and social pressure. Thus some activities may represent a net loss to the community, but nevertheless, they must be planned for.

In the sections below, the process which determines the types of activities needed in a city, and their grouping, is reviewed. Following this, the factors determining their accomodation as area uses will be examined.

Economic Functions

In order to determine the inputs to a land use model, the regional planner must first determine the level of an urban area in the metropolitan hierarchy, and what economic functions can be accomodated at that

level. In general, the degree of dominance is correlated to the amount of separation of economic functions within the area. The relative amount of some product or service that an area exports to other areas, indicates the degree of specialization.

The distribution of land use within the metropolitan community has been influenced strongly by functional separation. The functional or technological separation has led to spatial separation (Quinn, 1955). This, in turn, has led to spatial and social organization. Technology has provided the impetus for change in the habitat, and organization is providing a means for adjustment.

Schnore (1965a) points out that the spatial separation of home and work is a recent phenomenon, a product of industrialization. It supplemented migration and tended to strengthen the economy by its inherent flexibility. Within a central place there often are separate residential areas which may be referred to as suburbs (Douglass, 1925). However, if such an area were to offer employment to at least its own residents, then it would be categorized as a satellite. If this employment were, for example, electronics manufacturing, then this central place would have the specialized function of electronics manufacturing. In short, the suburb is a product of functional separation and is only one part of a city community, whereas the satellite community may have specialization of function and spatial and functional separation within that community. Furthermore, there may be differentiation of functions between one central place and another.

The above type of classification of function has not been defined previously. However, its use appears to be a means to determine some of the basic inputs to a land use model, namely the types of activities and

how they are combined. This problem may be presented best by four questions:

1. What functions or activities will be carried out in the community for its sustenance?
2. How many of these functions will be separated from each other, and in what manner?
3. What functions or activities will be carried out for export to the hinterland?
4. What functions or activities will be carried out for export beyond the hinterland?

The distinction between items three and four was motivated by Duncan et al. (1960) who pointed out that functions which service the region are tied to the region's fortunes, whereas specialized functions may be essentially independent of them.

Thompson (1963), in examining stages in contemporary urban growth, lists the following:

1. Export specialization.
2. Export complex.
3. Economic maturation.
4. Regional metropolis and/or technical-professional virtuosity.

Export specialization is the result of the growth of a single industry which gives way to an export complex with additional industry. Following this, the central place reaches economic maturity with the addition of service industry to reduce imports. Normally, the next stage in development is the achievement of dominance over the surrounding satellites and the hinterland. In some cases, an area may become nationally eminent in some industry. This is the stage of technical-professional

virtuosity. This stage may either precede or follow the metropolitan stage. It is apparent that during these developmental stages there is initially distinct functional specialization which tends towards diversification. It is possible that functional specialization may be retained or even extended. As expected, however, Harris (1943) found that metropolitan cities do tend to be diversified, rather than specialized.

Duncan et al. (1960), in considering the distribution of types of industry in cities of varying size, found that industries with large non-local markets tended to be concentrated in large cities. Since these cities tended to have a larger hinterland, this result is in line with the hierarchical theories of Christaller and Bogue. It should be noted that this is more applicable to service industries than goods industries, since some specialized goods industries not only have large non-local markets, but have little or no market even within the metropolitan community. Diversity of industrial activities in the metropolis (Duncan et al., 1960) may be due to:

1. Separation of function allowable due to the economy of scale of the large metropolitan community market.
2. Differentiation of functions due to needs and tastes generated by large cities themselves.
3. Separation of service functions from the household or goods industry permitted by the economy of scale of the metropolis population.
4. Separation of service functions from generalized service organizations.

Alonso (1964) referred to this separation of service functions as external economies, although as Duncan et al. (1960) point out in the fourth factor producing diversity, there may be no savings implied.

Referring to specific industries, Duncan et al. (1960) found that as

city size increased, extractive processing and local service industries tended to become less important than fabricating and non-local industries.

Many criteria have been used to determine a functional classification for communities. In most cases, this classification is categoric rather than corporate (Harris, 1943; Reiss, 1957), although Schnore (1965a) refers to a functional unit which is an organization of activities dependent upon still other activities. It seems that this type of classification of activities should be more useful as a model input than a categoric one since the latter is less stable over time and, unless very detailed, may not reflect need for public services or locational forces.

Whether categoric or corporate classifications are used, the measure usually is either occupational or employment data. Unfortunately, neither measure is clearly categoric or corporate (Harris, 1943).

An interesting extension by Quinn (1955) of the function concept is to examine diversity of function within areas of the city. Except for spatial differentiation, it may be immaterial whether satellite cities are contiguous to the central city. Alonso (1964) cautions against confusion of dispersion or decentralization within the city with national dispersion. If both of these thoughts are added to Bogue's metropolitan structure, it may be hypothesized that there is really a continuum between specialized parts of a metropolis and the metropolis and its satellites, that dispersion or decentralization within the metropolis is not basically different from dispersion within the metropolitan community, but that decentralization on the national level will have overall effects on the community, other than internal reorganization.

Thompson (1963) pointed out an application of the principle that spatially separated urban areas may function as one for some purposes, if

they have good communication between them. The example cited was the Chapel Hill-Durham-Raleigh triangle. Vance and Smith (1954) note also that air transport has tended to integrate dominant centers by movement of key personnel. As air transport systems improve, there are continuing functional adjustments by both separation and specialization.

In concluding this brief review and analysis of economic functions, it is appropriate to cite Ullman (1941): "The system of central places is not static or fixed; rather it is subject to change and development with changing conditions. Improvements in transportation have had a noticeable effect". Since functions are so closely tied to hierarchy, central place dynamics apply to function as well. Accordingly, Vernon and Hoover (1965) stated that the input-output for an area changes rapidly with time. Schnore (1965a) noted that the secondary and tertiary functions of fabrication, distribution, and control, are tending to decentralize within the metropolitan community as transport is improved and the level of service is made more uniform over the region.

Social Functions

As in the case of economic functions, social functions may be described as follows: separated spatially within the community, specialized in by the community, or differentiated by community. The last is much more important to social functions than in the case of economic activities. Social organization also often spans many metropolitan communities. This has given rise to Webber's thesis of the non-place urban realm which in many respects corresponds to the market area of the specialized function (Webber, 1964). It is not, however, of direct concern to the local urban planner except insofar as urban realm organizations are increasing at the

expense of local social contacts. Thus for some strata of the population, the local urban form becomes of lesser consequence.

Urban Form and Structure

The form and structure of an urban community are the physical and temporal framework for activities and communications. Form is the physical framework of facilities and structure is the temporal and spatial organization of activities. Form and structure exist to permit functions to satisfy community goals. Referring to Figure 1, the sequence of goals, objectives, functions, structure, and form may be noted. Planning is concerned with isolating those factors of value at the community level, formulating goals, and relating goals to form factors (Lynch and Rodwin, 1958). In this section, form and structure will be analysed, and in the following section they will be related to community goals.

Once the requisite activities for the plan area have been determined, the factors influencing their arrangement must be examined and incorporated into the area use model.

Each activity in its optimal location produces utility or return, but since each activity occupies a finite amount of space, the interaction of the activities requires utility to overcome the friction of space. It is the net product of utility return less utility cost that the community wishes to maximize. Thus the organization of activities in space, the amount and type of interaction, and the costs of interaction by type, are necessary inputs to an area use model.

In the sections below, a method of analysing the community organization, so that orthogonal components of the model inputs may be determined and quantified, is developed. The structure of the community is reviewed

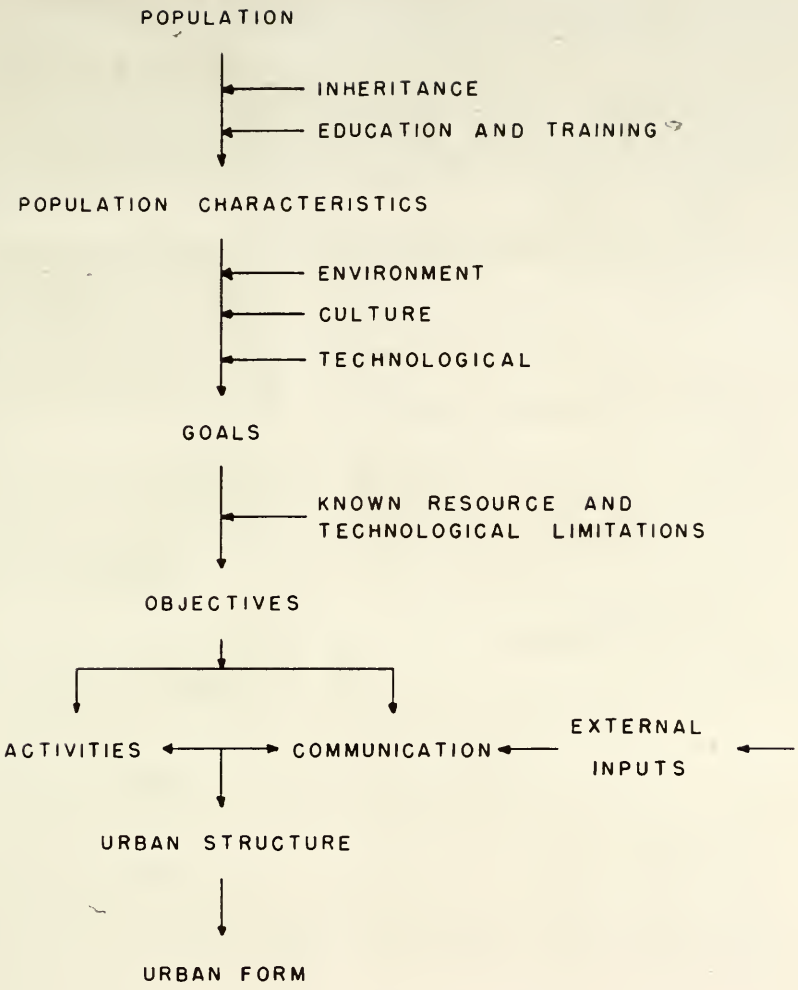


FIGURE I DEVELOPMENT OF URBAN FORM AND STRUCTURE

briefly, prior to a description of urban form - the product of area use allocation.

Urban form may be viewed as facilities in time and space to accomodate activities which communicate both through hierarchical foci and a network.

Since it has been assumed that the activities to be accomodated will be determined by prior studies, the quantity and type of elements or activities in the plan area are not discussed in detail. Focal organization and grain, although necessary for description of urban form, are not an input to, but rather output from, the normative program. Accordingly, these factors are examined only briefly. It is the intercourse between activities which is at the heart of area use arrangement, and thus communications are examined in detail. It was not the intent to place specific values on any of the communications, but to review all components, to determine their relative significance, and to incorporate the significant components in the model. In a later section it will be shown by cost data that transportation, and in particular person trips, is the most important factor. Accordingly, the generation of person trips is examined in some detail below. A second important communication factor, incompatibility, although difficult to quantify, is also outlined carefully.

Following the analysis of these communication factors, it will be shown that by utilizing the evaluation of community goals, an objective function for a normative program may be established. This objective function will include the maximization of activity return less the costs of transportation and incompatibility. In addition, the costs of adapting a

given use to an absolute location are examined and incorporated in the objective function.

Structure

Urban structure is the organization of activities in a temporal and spatial framework. The activities are dictated by the population strata of the local area, plus external inputs due to specialized economic and social functions. The urban complex is highly interdependent and its organization is a collection of heterogeneous but mutually complementary groups. As the community size increases, technology permits evolution of the organization by separation of activities from the home and differentiation of the activities, resulting in greater diversity of activity type and a more complex organization. The primary prerequisite of this organization is communication, since organization implies relationships.

There are two types of organizational units, corporate and categoric (Hawley, 1950). An individual changes organizational role with time, both daily and over his life span: a carpenter working for a contractor is a corporate member, at a union meeting he has changed to a categoric role, and at home he may revert to a second corporate role as a father.

Within a given community, either corporate or categoric groups may serve one or both of the following purposes: intracommunity needs, or intercommunity needs. Hawley (1950) suggested that the community is fixed by the maximum radius of daily movement to and from the center. This principle could be applied to communities at every hierarchical level by using daily communication to and from the center. Thus intracommunity services at one level become intercommunity services at a lower level.

The distribution and types of groups within the community vary with time. That is, the organization of activities has rhythm, tempo, and timing (Hawley 1950). Rhythm is the result of physical effects such as weather cycles and the cultural-physiological needs which result in habits, such as eating three meals per day. Tempo is the number of events per unit time, and timing is a combination of rhythm and tempo. The most prominent example of temporal effects on planning is the peaking of traffic volumes due to mass change of role within a limited time span. A far-reaching effect of rhythm on organization is the need for storage. When this is the result of seasonal differences, storage may be reduced by substituting transportation of goods between communities. This, of course, results in the greater interdependence of communities.

In reality, time presents the biggest planning problem, since organizational evolution prevents an equilibrium state.

Mitchell and Rapkin (1954) note that form generally lags behind structure. It will, in fact, inhibit the evolution of structure, so that the planner's responsibility becomes one of providing for urban form which will match some desired future structure. Since structure assumes a hierarchical ordering of groups, form must follow this structural grouping. Planning thus provides for desired group interactions, while preventing unnecessary inter-group communications links which may lead to both economic waste and Meier's (1962) communications overload.

Form

Lynch and Rodwin (1958) suggest that urban form is a function of element types and their quantity, focal organization, grain, and density. These criteria may be used to describe both area uses and communication systems.

Element types are either activity groups in area parcels or communications between the activities. The quantity of each element is determined by the community objectives, its size and environment, and by its input-output relationship to other areas. Density, grain, and focal organization formulate the pattern of these elements. In general, this form does not coincide temporally with structure, since it has the inertia of sunk capital costs and thus lags behind structure.

Focal Organization

The evolution of activity separation from the home has produced, within each urban community, focal centers in which these separated functions take place. In an equilibrium state, each focal center will have a cluster of separated enterprises in functional harmony. In addition, some foci may include specialized activities. If socio-economic intercourse were plotted for an urban area, it would peak at these foci and as a result the communication channels converge there. Friedman (1963) described the human settlement as a system of nodes and functional linkages. Surrounding each node or focus is a density field of functional interaction, in which the density declines with increased distance from the center.

However, it is important to note that an urban area is primarily a matrix of homes, on which are superimposed non-residential area uses grouped at focal centers of communication between the separated activities and the surrounding residences. In many cases, each activity within a focal center is linked to approximately the same area of residences as any other activity. This area will be referred to as a focal area. However, each home may still have some links to several focal centers, as shown in Figure 2. These foci are arranged in a hierarchical structure. Hemmens (1966) found that this focal structure can be shown by trips. There is

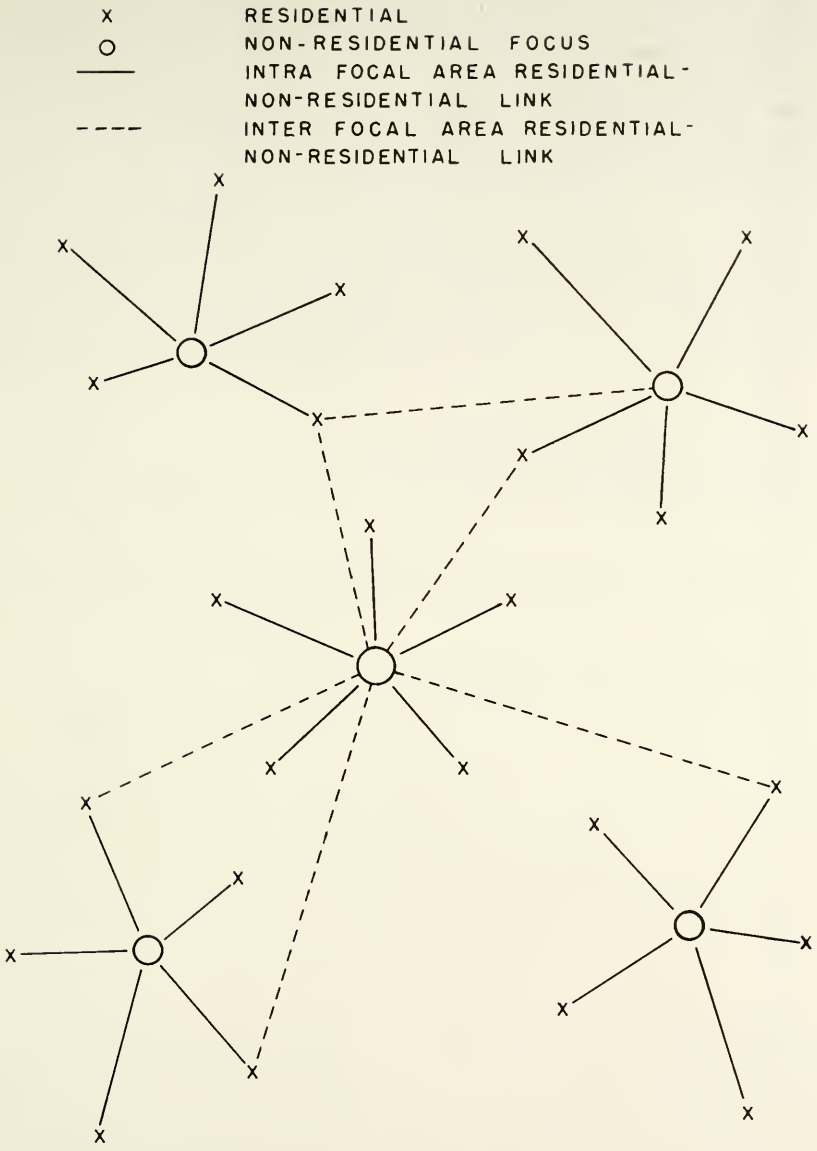


FIGURE 2 RESIDENTIAL - NON-RESIDENTIAL LINKS

only a small background of inter-focal area trips relative to intra-focal area trip volumes.

Urban areas can be characterized by several basic focal patterns as shown in Figure 3. In the United States, the most common focal patterns are as follows (Michael, 1966):

1. Single center cities exist in which much of the socio-economic intercourse occurs within one large focal area. There still will be some neighborhood foci such as schools, recreation, etc., but these are small in comparison to this central business district, and virtually all communications are oriented towards the center.

2. Linear or corridor focal areas often have developed in urban areas in conjunction with mass transit or rail lines. This type of development has been condemned as unplanned development, but Le Corbusier (1955) proposed this style in balance with other forms.

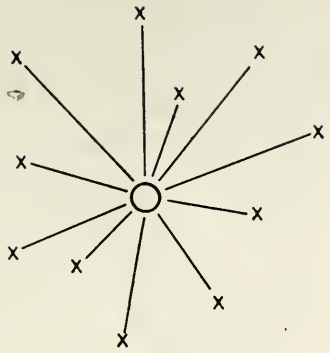
3. Satellite focal patterns have developed also, in which each satellite is a specialized economy with sufficient employment for its own residents.

4. The scattered land use pattern, often referred to as suburban type development, has a number of small foci in which there is less interdependence than for satellite systems, and more dependence on the city center.

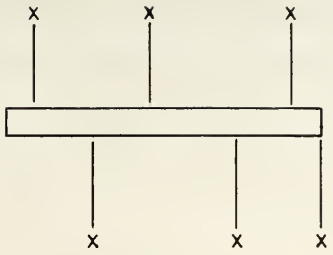
Many cities do not exhibit any one of these patterns, but rather a combination of several. For instance, early American cities often developed with a central core crisscrossed by linear focal areas along transportation lines. Subsequently, satellite and scattered development may have been added.

In addition, the development of ring roads concurrently with increased mobility suggests that a fifth category of curvilinear or ring focal areas could be added. This principle was used in planning the new town of Germantown, Maryland (Life, 1965).

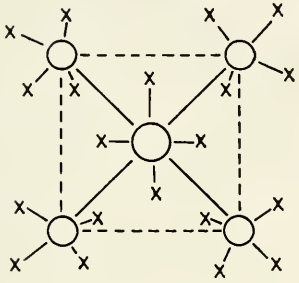
Environment affects focal development because of water and topography. These factors are controlling both esthetically and by their interaction



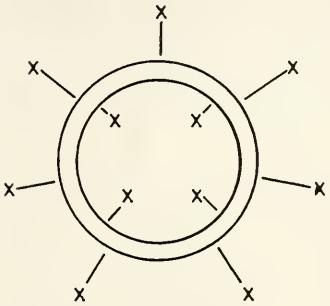
SINGLE CENTER



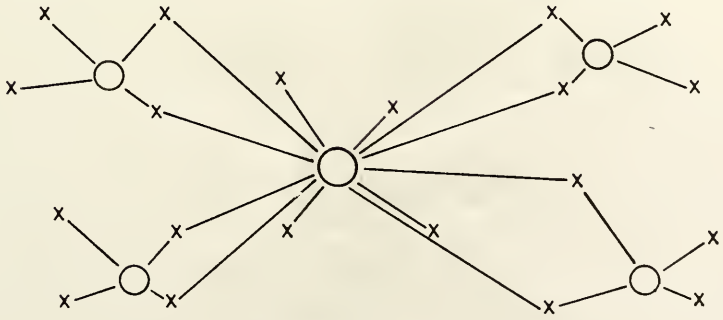
LINEAR OR CORRIDOR



SATELLITE



RING FOCUS



SCATTERED

FIGURE 3 BASIC FOCAL PATTERNS

with technology, particularly communications. However, this latter interaction term is decreasing in relative importance as engineering technology progresses.

Isard (1956) regarded transportation technology as one of the principal factors in economic activity location. It is significant also in social communication (Willmott and Cooney, 1963), but the latter is more important at the neighborhood level than at higher levels. The predominant type of transportation has had a distinct influence on both city location and growth. Linear type development was common along transit lines in earlier cities, but with the introduction of the limited access subways and freeways, a nodal form has been superimposed on this linear type. In addition, the automobile has permitted low density development of interstices.

Population affects focal development through size, growth rate, and ethnology. Initially, all communities develop a single center for separated socio-economic activities, and later tend to evolve towards other patterns. In addition, Schnore (1965b) noted that stratification of residential areas by class and ethnology does not occur in smaller centers to the same extent as in the older larger cities. Rate of growth can affect development, particularly if focal units do not have definite boundaries, such as topographical breaks. Ethnological groups may tend to form separate residential and even socio-economic areas, but this is more evident in grain. In western civilization the advancement of transportation has permitted greater interdependence, and thus has had a great impact on the organization of the social and service facilities of a community. This will be one of the important factors in allocating separated activities to the proper hierarchical level. Webber (1964, p.107)

predicted that these patterns of functional interdependence will become increasingly complex as major communication developments open "unprecedented possibilities for wholly new spatial patterns".

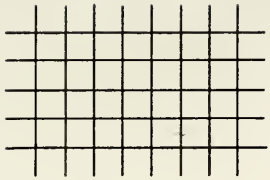
The pattern formed by communication lines is indicative of the focal organization. However, it is not an exact picture because of the time lag between structure and form.

Most communication lines follow the street pattern but in some cases easements permit them to cross other land. Lynch (1962) classified street patterns as grid, radial, ring, branched, and linear (see Figure 4). In many cities, the actual pattern is a combination of the above. However, the synthesis can change profoundly the characteristics of the systems. Examination shows that only in the grid, ring, and linear systems are all elements on the same hierarchical level directly linked. The ring system, on the other hand, precludes links between hierarchy levels. However, by combination of different types, communication can link any two nodes.

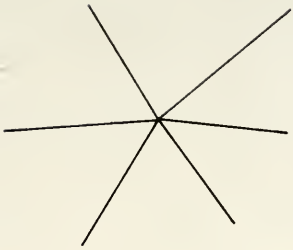
The communication system itself is composed of nodes and links. Since each break in transport incurs a cost, then optimization implies analysis of both channel link length and number of nodes. This communication system also has an effect on the allocation of activities to focal units, and thus any solution must consider both problems simultaneously, or by some iterative process.

Grain

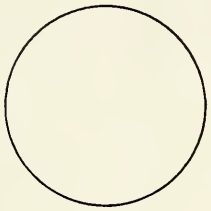
Grain refers to the texture of an urban area, that is, degree of heterogeneity of the elements, their arrangement, local density, and definity of boundary. Each focal area may be said to have a texture which is closely correlated to the focal arrangement. Thus there is a loose hierarchical system of grain corresponding to that of focus.



GRID

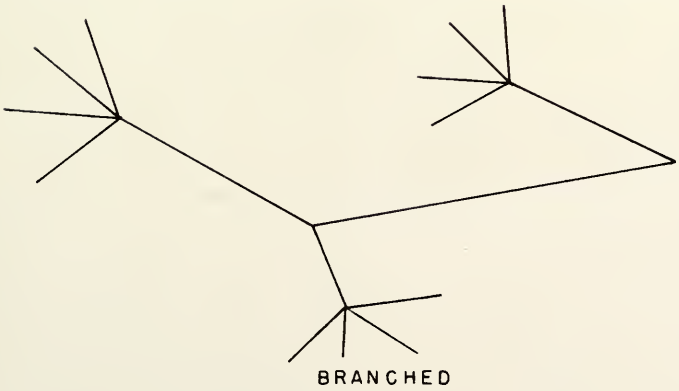


RADIAL



RING

LINEAR



BRANCHED

FIGURE 4 STREET PATTERNS

At the metropolis level, grain could appear as the pattern of a central retail area contiguous to wholesale, financial, and civic areas which in turn are surrounded by residential areas interspersed with industrial, educational, research, and recreational areas. All areas are individual elements whose characteristics, together with their locations, comprise urban grain. At a lower level the grain of a town could be the residential neighborhoods surrounding a heterogeneous town center with its retail, medical, recreational, civic, and industrial activities. However, if each of these activities were separated into more homogeneous but contiguous areas, the town focus still would be its center, but the grain of the town center would differ. Again, if each of these separate activities were placed in towers surrounded by open space, the distinct delineation of boundaries of each element and the introduction of open space would both alter the grain. The grain could be modified also by compressing the size of the town center, thus increasing the local density. Finally, grain would be altered by the introduction of new elements.

Density

Density of the urban pattern has two levels and two dimensions. Furthermore, it may be measured in several units. The two density levels refer to the average density of the total area, and to the local density of a small sub-area. Density has the dimensions of volume and spatial separation. It can be expressed in terms of persons, behavioral units, activities, social intercourse, and many other units. In general, most density functions of a focal area, such as a plot of intercourse versus distance from the urban center, are bell-shaped curves. If such a curve were plotted for the dominant center it would tend to be symmetrical, and

the curve for all sub-dominant and lesser focal areas would tend to be skewed towards the city center. The degree of dominance of the focus would be indicated by the skew, the interdependence of the areas by variance, and the local distribution of intercourse by kurtosis. Clark (1951) found that North American cities show a low-density gradient, indicative of a dispersed development.

Horwood (1962) states that the density of an urban settlement can be described by a hyperbolic parabola:

$$P = K/_{r}n$$

where: P = density in population per unit area,

r = distance from the focus of urban centrality,

K and n are empirical constants.

This density curve, however, is discontinuous at the central business district with its absence of population. This may not hold true, though, for social intercourse density.

Density of urban areas traditionally has been measured by the dimension of volume or area. Yet, transportation assignment techniques and accessibility locational analysis indicate that the spatial separation on the time scale, and thus the time density, may be very important. Unfortunately, the latter is a function of the mode of communication. Webber (1963a) suggested that Los Angeles may still have as many linked establishments within a given time radius by automobile as New York. This would not be hypothesized for the walking mode. Chapin (1965) suggests that the accessibility standards of non-residential area design be determined primarily by time, and in the few cases in which distance was suggested, time by the appropriate mode could be used equally well.

Persons or dwelling units per unit volume or area have been the most common density measures in planning. Recently, some regions have used maximum number of dwelling units per unit area to control residential development (Whyte, 1964). Previously, most zoning was based on a minimum area per dwelling unit. Tuemmler (1954) noted that Prince George County, Maryland has set both minimum and maximum density limits on development.

Densities are correlated to the element types and their quantity within a focal area. Within a small density range the element types may not change but their size or the amount of open space decreases. But if the density changes significantly, then the element types usually change also. For instance, in the residential areas, large increases in density lead to an increase in the proportion of multi-family dwelling units, and their unit area use decreases. This relationship is clearly exhibited in the Federal Housing Administration's Land Use Intensity Scale (Hanke, 1966). This scale outlines minimum residential standards in terms of floor area, open space, parking area, living space, and recreational space. As the use intensity increases, the optimal element changes from one-story detached units through town houses, to multi-story apartment. This method of regulation is indicative of the trend away from lot-by-lot control to density zoning, and is particularly useful in regulating three dimensional development in terms of area.

The central business district (CBD) density is a function of metropolitan age, population, resources, and technology. As the area population increases, more and more activities compete for space in the CBD due to its accessibility. This competition was expressed graphically by Isard (1956) as a plot of area rent versus distance from the center, for

each of several activities. Beyond some limiting distance from the CBD center, however, accessibility is less than in secondary foci, and thus the CBD area is limited by the existing communication systems. Within this limited area, activities compete for space until their space preference exceeds their accessibility preference, that is they are limited by the area rent. As the density of the area increases, then, some groups of activities leave the CBD while others tend to separate further into more homogeneous groups. Ogburn and Duncan (1964) found that over a population of 1,000,000 a city's CBD tended to remain at approximately one square mile in area, although the density increased.

Wingo (1963) suggests that communications technology may permit decentralization of this urban complex, eventually. This will occur only if improvements in communications exceed the increase in need for accessibility.

Activities

The most important elements for input to an area use model are the economic and social functions which must be accomodated. These may be referred to as activities which occur "within particular adapted spaces" (Chapin, 1965), and communications which take place between these adapted spaces. The latter will be examined in a later section.

Activities often are thought of in terms of the land they use. Recently, the Urban Renewal Administration and the Bureau of Public Roads developed a Standard System for Identifying and Coding Land Use Activities (Urban Renewal Administration and Bureau of Public Roads, 1965). The basic premise of the system was this: because of the multiplicity of uses of land use data and the desirability of standardization of coding

for reuse for these different purposes, different characteristics should not be combined in the original coding. Instead, a wide variety of data would be collected under three categories; activity, parcel, and structure. Then for any given purpose, the required data could be retrieved and combined. Furthermore, the use of standardization permits research on data from several urban areas.

For model purposes, the above type of data system would seem to be the best available. Three questions remain to be answered with respect to the final form of the activity-land use inputs to an allocation model; how much of each category of activity is desirable or needed, what activity-associated data are required by the model, and most important, how should the data be combined as inputs? The desired types and quantities of activities will be determined by the community objectives in terms of; the policy on economic functional separation and specialization, the degree of dominance of the community, competition from both inside and outside the metropolitan communities, regional characteristics, and finally, the desired social functions. The associated data which are needed as allocation model inputs are; adaptability of land parcels, and communications. These data usually are combined for land use models according to an industrial or residential grouping of activities. Vernon and Hoover (1965) point out that activity classification must be diverse enough to establish a pattern but still sufficiently homogeneous to have some locational forces. Extending this concept, they suggest that activities might be classified by the dominant locational force. Czamanski (1965) supports this view, and stresses that one of the locational forces is the symbiotic and commensalistic relationship with other industries. That is, location should be by groups of functionally complementary

activities.

Activities are in reality the trip purposes of transportation planning. Curran and Stegmaier (1958) list the following possibilities:

1. Work.
2. Business.
3. Medical-dental.
4. School.
5. Social-recreational.
6. Eat meal.
7. Shop.
8. Change mode.[1]
9. Serve passenger.[1]
10. Home

1 - these are not applicable

These categories would be subdivided for area use design, particularly at the neighborhood level. For instance, Foley (1950), in a study of local facilities, separated elementary and high schools. The classification of business district activities is somewhat more difficult. It is desirable on one hand to minimize the amount of data to be acquired and processed, while on the other hand permitting allocation of the activities by the appropriate groups. Supermarkets are an example of a major facility found in most focal centers, but yet the specialty store will not be found in the lower level shopping centers. As a result, where the number of trips to a shopping center may be sufficient data for communications planning, a more finite classification of the trip purpose or activity groups may be required for area use planning.

Throughout urban evolution there has been a progressive change in the location and grouping of activities. This is most evident for the economic activities or functions. However, there have been similar changes in social activities as well. Hawley (1962) refers to the change from heterogeneous groups of activities to homogeneous groups. That is, functions, both social and economic, have been separated from the home and now are executed in spatially separate areas.

This change in grouping has been made possible by improved transportation. Although the improved transportation is a necessary condition, it is not sufficient. Because of the dynamic aspects of the problem, optimal grouping of activities will remain one of the major difficulties in applying any land use model.

Communications

Communications have been defined above as any intercourse between particular adapted spaces. Any given space may be adapted to a variety of uses, but it is the relationships between uses which is the problem of planning (Gallion and Eisner, 1963).

If activities are considered as nodes, then communications may be viewed as links. The linkages function as attractive forces in the movement of information, goods, and persons, and as repulsive forces (Lynch, 1962). Repulsion may be expressed in many ways, but it results in maximum density limitations and/or preservation of open space. Meier (1962) postulated that repulsive forces have two distinct components, a need for a minimum distance to sustain life, and the competition with strangers at great distances. These instinctive forces are the ethologist's critical distance (Ardrey, 1966) and Lorenz's communal warfare (1966).

However, the repulsive forces are overshadowed by the attractive forces, which tend to minimize the friction of space and result in urban agglomerations. These attractive forces comprise the information, goods, and person flows that link activities. Not all of these links are desirable, of course. Some of the external effects of activities are communications in the form of smoke, noise, and other nuisances, which the community wishes to minimize.

Communications could be described in terms of the following properties:

1. Origin.
2. Flow quantum.
3. Mode.
4. Destination.
5. Time of inception of process.
6. Duration of process.
7. Time of start of reception.

The origin and destination of communications are particular adapted spaces, and the originator and recipient are individuals, firms, or establishments.

The flow quantum in a communication may be a person, good, or symbol. In addition, a carrier may be used to facilitate the movement, such as a truck or a radio carrier wave.

The general channels of communication might be classified as subterranean, terranean, aqueous, and aerial. At some frequency specialized channels are required, that is, channels which carry a less heterogeneous group of vehicles or flow quanta. The mode is characterized by the vehicle and/or the channel. The specialized channels and/or associated

vehicles and flows that man may construct or utilize for urban areas are shown in Table 1.

Table 1. Communication Channels

Terranean	Sub-terranean
Belts	Electrical Conductors
Pedestrian	Power
Solids	Telecommunications
Electrical Conductors	Pavement Subways
Power	Pipelines (non-pressurized)
Telecommunications	Pipelines (pressurized)
Flumes	Oil
Liquid	Gas
Solids in Fluid Carrier	Water
Pavements	Specialized Products
Wheeled Vehicles	Rail Subways
Air-cushion Vehicles	
Pedestrians	Aerial
Rails	
Wheeled Vehicles	Flight Channels
	Helicopters
	Aircraft
Aqueous	Light Waves
	Modulated Radio Waves
Recreational Boating	Direct
Shipping	Tower or Satellite Relay
	Power Waves

Some of these modes serve only inter-city communications, while others are only potential modes, to date. However, they all are possible elements to be considered in design.

The time factors associated with communications are of interest to the designer for two reasons, peak volume and time costs.

Communication Generation Models

The causative process leading to communications can be represented as shown in Figure 1. The causal variables of the model could be the population characteristics of each stratum, and resources. These factors can be measured for the immediate area being planned, but not for the urban realms. Since urban realm population characteristics and resources

affect non-residential activities within the plan area, then the planner should consider these activities and local population strata characteristics and resources.

It has been shown above that communications are links which serve land uses. In other words, a communication is the result of the interaction of two activities, expressed, for instance, as the from-to purpose of a trip. A model could be built to represent communications between any two activities in each of the categories; goods, persons, and information flows. This would provide the second major group of inputs to the area use model, that of communication. The process is complicated by persons serving as vehicles within vehicles in the transfer of symbols and, to a minor extent, even goods. However, the cost analysis below will show that the major considerations in area use allocation are the person and goods flows, which are considered in more detail below.

Transportation planning normally has considered trip generation as the first of a three stage process. In this stage, correlation, regression, and occasionally analysis of variance techniques are used to develop equations which indicate the number of trips generated per zone between two types of activities.

In the second and third stages of transportation planning analysis, the predicted trips from the generation stage are distributed and assigned to a road network. In this process, it is assumed that trip generation rates for present land uses patterns will form the basis for predicting future trip rates for both existing and forecast area uses. Some transportation planning studies have considered density and distance from the CBD in the generation analyses (Wynn, 1959), as partial recognition of the interaction of trip generation and urban patterns.

In all generation models, the following assumptions are made:

1. The aggregate of individual trips is systematic and thus capable of being modelled.

2. Trips can be correlated to independent variables.

3. The independent variables can be predicted.

4. The resultant equation formed from the correlation of independent variables to trips can be used to obtain a more detailed and/or reliable measure of trips, with estimates of the independent variables, than if the trips were estimated directly.

The first assumption in turn implies that trip generation equations are sensibly constant over time, that is, there is no change in either the variables used or their parameters. If the significant variables differ over time, one might attempt to compensate for the change by adjusting the parameters.

The first and perhaps most important problem of constructing a generation model is the classification of trips. In nearly all cases, the classification chosen is by a from-to purpose by a given mode. This from-to purpose in reality refers to the type of activity at each end of the trip. Since an average of 60 percent of trips are home based (Sharpe et al. 1958), one of these activities often is home. Despite the knowledge that socio-economic class factors influence trip making, the residential or home class is rarely subdivided (see for example, Indianapolis Regional Transportation and Development Study, 1966). This may not be a serious drawback for transportation processes in which the model is calibrated for each case, but could be a problem for a synthetic or a normative model. Oi and Shuldiner (1962) noted that this use of zonal averages introduced bias. Janes (1966) showed that trip generation rate distributions for households are highly skewed. A similar problem arises with respect to non-residential area use trip classifications. But, the degree of

classification and data precision must be balanced against net benefit of the precision.

In most cases, trips are between residential and non-residential activities. Prediction then may be based on either population strata characteristics or area use characteristics, but the trip generation is based on the interaction of characteristics of each.

Partitioning of trips into person trips and goods movement may be desirable. Within an urban area, goods movement is either by special modes or comprises a relatively low uniform load on highway facilities. In the Puget Sound Regional Transportation Study (1966), it was found that 8.4 percent of the trips were by commercial vehicles. The relatively lower peak volumes of trucks indicates a lower marginal facility cost, but since time costs in terms of driver time are high, the goods movement is still an important segment of communication costs.

Factors Limiting Trip Generation

A communication is an ancillary activity. Even pleasure riding is an adjunct to observation or relaxation. In order to understand factors which produce communications, the relationship between location and activities should be observed. If all the activities which a person wishes to participate in are at one point in space, there will be no communication. In fact, however, there has been a steady trend towards greater urban, national, and international organization, and thus to an increased need for communications. As noted previously, activities have tended to become separated and specialized in particular adapted spaces due to economies of scale and to inequitable distribution of natural resources. Further, there has been a differentiation and spatial separation of activities due to man's social organization. The resultant trend to

increased communication, however, has been restricted by resource costs. The resources needed are time, human energy, natural, and space. From the economic viewpoint, the causal factor of communication is the desire for activities. This desire is not entirely fulfilled because of the costs of the joint commodity: the activity and its ancillary communications.

Factors Contributing to Desire for Trip Generation

Land use or activity characteristics plus population strata characteristics are the principal factors utilized to estimate the desire for generation of either person trips or goods movement trips. The land use-activity characteristics may be due to external factors or to the local population strata. In general, activity characteristics are preferable to land use characteristics for predicting trip rates, because of the time lag between activity and form. In many cases, however, population characteristics may be best theoretically for trip generation, because they are causative.

In addition to the factors contributing to desire, the restraint by the cost factor must be considered in order to arrive at a prediction of trips.

Causative trip factors are correlated to other factors which may be measured more precisely with less bias, or at lower cost. When this occurs, these symptomatic variables may be substituted for the causative variable, but despite their accuracy when the model is calibrated, they may not provide the best model for future prediction. Consequently, for any trip model, a balance between the bias, precision, cost, and causality of factors must be obtained. In a normative model which is to minimize travel, this is vitally important. The functional form of the generation model should contain both the main effect of each factor, and the first

or perhaps higher order interactions.

Trips serving the urban area can be separated into intra-community trips and external-internal trips. The number of the latter is dependent on the delimitation of the community. If the community limits are defined as the bounds of the metropolis, and if the population is in excess of 1,000,000, the number of external-internal trips will be approximately 5 percent of the total trip volume (Schuster, 1964). However, as the community size decreases, external-internal trips become a more significant factor in urban trip generation, amounting to approximately 20 percent of total trips at a population of 100,000. In most models, external-internal trips are accounted for by a percentage expansion of the number of internal trips. Although this has proved to be a practical technique, some major generators within the area, such as airports, yield a very high percentage of such trips. Since these trips are not included in the data from home interview origin-destination surveys, they are difficult to analyze (Keefer, 1966).

Population Factors. - Auto Ownership. - The number of cars owned by a population group "is the one variable which exhibits the closest association with reported trip generation rates", according to Oi and Shuldiner (1962, p.86). However, they point out that a high correlation coefficient does not imply a causal relationship. A better multiple correlation of determination might be obtained between trips and the population strata characteristics which produce the motivation to make trips and their respective ability to pay for cars, than between car ownership and trips. On the other hand, these data likely would be more difficult to obtain.

Oi and Shuldiner (1962) point out that auto ownership has been shown to be correlated significantly not only to trips, but also to distance from the central business district, household size, and dwelling unit type. Wynn (1959, p. 16) suggests that level of income is much more significant than car ownership. By placing population in four income classes and comparing 1948 to 1955, he found:

1. That for the three higher income brackets the number of cars per resident was almost constant.
2. That between 1948 and 1955 there was a definite tendency for cars per resident to approach a constant in all income brackets.

This would seem to indicate that as car ownership approaches a saturation point, its coefficient of correlation to trips will decrease (see Figure 5).

Family Size. - Oi and Shuldiner (1962, p. 85) stress the correlation of family size to trip generation rates (see Figure 6). Stowers and Kanwit (1965) found a higher standardized regression coefficient of trips to family size than to autos owned (see Table 2). They found a linear relationship in both cases.

Distance from Central Business District (CBD). - The distance from the CBD has been suggested (Wynn, 1959) as an important factor in trip generation rates. Oi and Shuldiner (1962, p.95), however, have shown that if autos owned and household size are factors in the trip generation equation, then the importance of CBD distance is negligible.

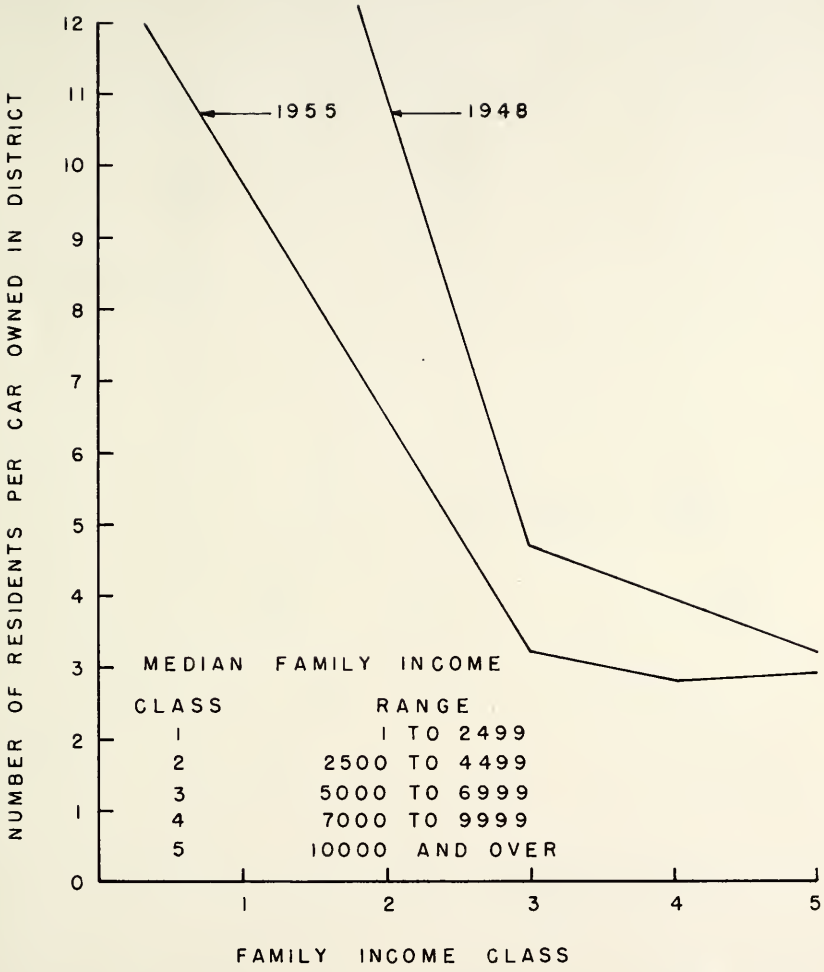


FIGURE 5 CAR OWNERSHIP RELATED TO FAMILY INCOME, WASHINGTON, D.C.— 1948 AND 1955 (WYNN 1959)

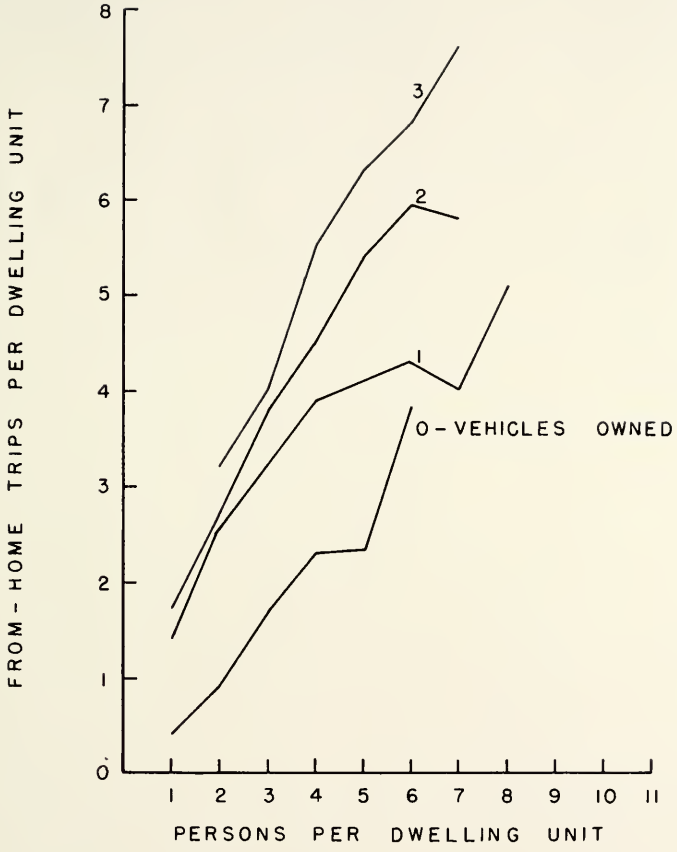


FIGURE 6 TRIPS VERSUS PERSONS PER DWELLING UNIT BY VEHICLES OWNED (OI AND SHULDINER, 1962)

Table 2. Ranking of Characteristics in Order of Significance.

Variables	Beta Coefficient	Rank
Family Size	0.29	1
Autos Owned	0.23	2
Income	0.14	3
Stage in Family Life Cycle	0.13	4
Occupation	0.11	5
Density Neighborhood	0.10	6
Distance From CBD	Insignificant	7

(Stowers and Kanwit, 1965)

Income, Occupation, and Social Status. - Stowers and Kanwit (1965) found that income and occupation ranked third and fifth, respectively, in explaining the variance between households in trip generation. Note that this was in terms of a standardized regression coefficient. Oi and Shuldiner (1962, p.104) point out that income often is deleted from trip generation equations because it is correlated to other factors which are, in turn, more closely correlated to trips. However, they did conclude that income has at least a partial effect on trips. In order to analyze the effect of occupation on tripmaking, Walker (1966) compared average trips by persons in each of eight occupation categories as shown in the Chicago Area Transportation Study, (CATS) and the Puget Sound Regional Transportation Study (PSRTS). This showed a small but consistently higher trip rate for PSRTS in all classes. However, when the data were stratified to eliminate household size and auto ownership effects, the difference in trip rates both by occupation and by city became striking (see Table 3).

Table 3. Trip Production by Occupation and Cars per Household for Households Having Three Persons (Walker - 1966)

Occupation of Head of Household	Trips per Household CATS 1956 (Stowers)			Trips per Household PSRTS 1961		
	0 Cars	1 Car	2 Cars	0 Cars	1 Car	2 Cars
Professional	5.29[a]	6.60	9.50	7.70	8.25	11.69
Manager	3.71[a]	6.84	9.53	6.01	9.43	11.90
Sales	5.75[a]	6.32	8.06	5.40	10.69	13.60
Craftsman	3.76	5.24	7.70	3.77	7.72	9.82
Operative	3.53	5.09	8.95	3.62	7.44	10.08
Clerical	3.67	5.40	6.82	4.93	8.30	10.77
Service	3.80	5.96	6.10	5.17	9.36	10.64
Laborer	3.32	4.83	b	3.93	7.64	9.57

[a] Represents fewer than 10 observations

[b] No observations

Several other economic status factors also have been proposed as trip estimators, such as rent and housing conditions. But, Oi and Shuldiner (1962, p.108) could find no reliably consistent relationship.

Other factors, which often are considered in trip estimation, are social status measures (James, 1966; Schmidt and Campbell, 1956; Oi and Shuldiner, 1962). James, for example, combined occupation, land use pattern, and distance to the CBD to derive a social status variable. The combination permits some consideration of the interaction of the social status components.

Another social factor proposed by Stowers and Kanwit (1966), and ranked fourth in importance (see Table 2), is the "stage in family life cycle".

Population Size. - Sharpe et al. (1958) note that population is highly correlated with trips. Its lack of prominence as an independent variable in trip generation may be explained by its high correlation to

other factors. In the Indianapolis Regional Transportation and Development Study. (IRTADS). the correlation coefficient of population to cars was 0.937 and to dwelling units, which has also been used as a factor, 0.962. Population may be a good predictor of future trips, even if it is not the best estimator of present trips, because of its causal nature.

Land Use-Activity Factors. - Employment. - Of all trip types, the work trip is the most important to planning. It comprises about 40 percent of total trips, and an even larger percentage of urban travel, and most work trips occur within a very short period of time. This in turn means that proportionally greater facility capital costs, relative to those for other trip types, must be assigned to the work trip to account for the highly peaked demand. The higher cost is justifiable since the work trip is a productive trip and thus is not as sensitive to time or other resource costs as many trips are.

The most accurate indicator of work trips is the employment level, and this is used in nearly all cases to measure work trips attracted to non-residential land. The work trip is a change-of-role interaction, usually from home to work. Lapin (1964) found that the volume of trips to industrial land is correlated closely to employee density. A survey of 50 major industries (Keefer, 1966) showed that there are less than 5 percent non-work trips to industrial sites. Of the trips to industrial land, trucks formed a surprisingly small part, averaging 3.52 truck trips (0.92 light and 2.60 medium and heavy) per 100 person trips. Even considering a weighting factor for trucks, truck impact on traffic would seem to be much smaller than normal auto traffic, particularly in view of the latter's peaking tendency. Larger plants tended to have less truck travel, probably due to reliance on rail and water transport. Also,

workers tended to use mass transit more to reach the bigger plants.

Area. - Area can be used as a trip indicator so long as it is properly partitioned by the type of activities accommodated. Unless the partitioning is very definitive, the predicted trips may be inaccurate.

In the practical application of area as an indicator, there are several problems. First of all, floor space usually is most closely correlated to trips, but this information may not be as readily available as the net or gross parcel area. Secondly, multi-level buildings and corporate firms may have many diverse uses. Furthermore, area use per person or per unit of trade or manufacture changes very rapidly over time.

There are several means of aggregation of area to derive trip rates. In Table 4 (after Shuldiner, 1966) there are seven categories of land use trip generation rates given. Although this is a common division of land uses, other approaches have been suggested. Mitchell and Rapkin (1954) present the thesis that trips may be a function of an area which encloses all possible destinations within walking distance of the trip base. The trip base may be either a land use or the point of departure from a vehicle. As an example, they point out that a unique business may attract trips to an area. In most people's own experience, there have been trips made to some distant area for a special product, and on that same trip convenience goods were purchased. Mitchell and Rapkin suggest that in "persons movement, the emphasis should be on the relative independence of establishments as destinations which attract travel, and on the attractive power of various combinations of establishments". This could serve as a good guide to land use classification. The two different approaches could be summarized as land use classification by:

1. Single Activities.

2. Complementary Groups of Activities.

Table 4. Summary of Person Trip Generation Rates for Ten Metropolitan Areas. (per acre) (Shuldiner - 1966)

Metropolitan Area	Resi-dent.	Com-mer.	Ind.	Pub. & Quasi Pub.	Tran-port.	Public Bldg.	Public Open Space
Tucson	18.2	134.3	3.9	14.3	-	-	-
Twin Cities	26.5	187.9	12.6	17.4	-	60.1	3.5
Corpus Christi	30.5	174.4	10.6	35.3	-	-	-
Pittsburgh	23.9	157.8	24.6	15.9	21.3	46.1	2.3
Chicago	48.5	181.4	22.0	12.4	8.6	52.8	4.2
Detroit	29.1	271.2	37.2	16.5	-	32.8	3.4
Baltimore	18.7	121.4	8.2	9.4	-	-	-
Ratio, high/low	2.7	2.2	9.5	3.8	2.5	1.8	1.8

Density, City Form, and Structure. - The local configuration of area uses has a restraining effect on trip generation because of costs or friction of space. Oi and Shuldiner (1962) noted that in the older, larger cities where travel is more difficult, trip rates are lower. For example, the rates for Chicago and the Puget Sound Region are compared in Table 3. The above factors may account for some of the variation in trip rates for different cities which must be considered in order to calibrate trip rates for any synthesis such as those required in a normative model.

Considering only one city, Wynn (1959) found that the "isolation" in newly developing areas had a restraining effect on trips. After eliminating other variable effects, Oi and Shuldiner (1962) could find no discernible relationship of density to trips, except when one-person households were excluded. Stowers and Kanwit (1965), using a small sample, found a standardized regression coefficient of 0.10 and rank of sixth in

importance (see Table 2) for density effect on trips.

Type of Dwelling Unit. - The type of dwelling unit has been shown to relate to trip rates (Cowan and Walker, 1964). However, this effect is reflected by other factors and is not used often in trip generation equations.

Communication Substitution

There often are several channels of communication which might serve the same activity. In fact, Artle (1963) points out that there can be two forms of substitution in communication, as follows:

1. One channel for any other of the set of feasible channels.
2. One set composed of channel and receiver of communications for any other of the feasible sets.

In addition, Isard (1956) noted that communication inputs may be substituted for resources when economies of scale exceed the communication costs.

Memmott (1963) suggested the following potential channel substitutions for goods or persons transportation:

1. Observation of an activity by visual channels.
2. Non-physical participation in an activity by visual channels.
3. Conferences and lectures by visual and audio channels.
4. Relaxation (in some cases) by visual and audio channels.
5. Business contacts by visual and audio channels.
6. Information transfer by visual and audio channels.

In each of these cases, transportation is supplanted by a message-carrying energy medium. But the substitution of the message is feasible only in place of transport of a person or a record. Artle (1963) discussed a far-reaching extension of the above, that is, remote control of production using a medium such as closed circuit television plus electrical controls.

This now is commonly applied within plants and even between plants. If it could eliminate or reduce the volume of work trips, communications and present urban area patterns could change radically.

Memmott (1963) suggested the following factors which may have an influence on substitution:

1. Purpose of communication.
2. Location.
3. Time (particularly with respect to peak volumes).
4. Income.

The last factor might be stated more precisely as the relative utility of the resource costs of the relevant channels to each user. As a fifth factor, technological and sociological changes must be added for the dynamic case.

Meier (1962) found in a survey of communications that telecommunications are growing at the fastest rate and there is a tendency towards substituting symbol transmission for person transport. Also, he found a tendency towards faster growth in bulk shipment, reflecting an economy of scale in transportation. Since person-to-person communication is becoming relatively less efficient, Memmott's prediction of a sharp decrease in such contacts seems entirely reasonable. Meier's finding of a finite limit of human time for communications (1962) suggests that as more efficient forms of communications emerge, the traditional modes must decrease in importance.

Operating and Performance Standards

Some of the communications occurring between activities are by-products of the activities and their desired intercourse. Each activity may be thought to produce certain levels of by-products which will be

referred to as its operating standards. Many of these by-products, such as smoke and noise, are nuisances and thus incur a utility cost. Accordingly, performance standards have been used to restrict the degree of transmission of these by-products. In some cases, private or perhaps even public capital is employed to reduce the level of transmission. Thus the operating levels of a given user may be lower than the performance standards for that activity. Turning to a given land parcel, it may be found that performance standards have been set for use of that area. If a user's operating standards are lower than the given performance standards, or if the operating level can be reduced below the standards by expenditures on smoke or noise abatement, et cetera; then the activity can be permitted to use that parcel. If private as well as public costs are to be considered in a normative model, operating standards, rather than performance standards, should be input to the model.

Often the impact of these external effects has been reduced by the application of permitted or prohibited use zoning. This is based on the premise that individual industries of the same type produce similar by-products. The net result is that the incentive for industry to reduce these external effects may be small, and problems may arise as new uses develop and older uses alter their operations. Furthermore, this type of zoning tends to produce inefficient segregation of uses according to type.

Recently there has been a trend towards regulating use allocation according to the expected type and degree of external effects. Each area is zoned to meet certain performance standards, that is its set of external effects must be equal to or less than the corresponding set of

standards. For ease of application, Sharpe (1960) suggested that permitted use lists be included with performance standards but any use could still be included in the zone provided that it met the required standards.

There are two major problems associated with performance standards, namely the need for an initial and continuing assessment of a use's performance, and a means for enforcement of performance standards once a use is permitted. The measurement problem will be reviewed briefly below in the coverage of each external effect. The problem of enforcement is not exclusive to performance zoning since changes in operation procedures can occur whether zoning is by permitted uses or performance standards. However, if allocation costs to the community due to incompatibility (difference in operating standards) are known, then a use which rises above the zoned performance standard can be taxed to make up for that loss. This procedure will be covered more fully in areas for further research. The net result of such a procedure should be a dynamic zoning based on then current incompatibility costs. It does, however, require a continuing assessment of performance.

The operating standards which are of interest herein are only those relating to external effects which vary according to location. The following groups will be discussed:

1. Hazards.
2. Vibration.
3. Noise.
4. Odor and Gases.
5. Heat, Glare, and Lighting.
6. Dust and Smoke.

7. Electrical Interference.

8. Traffic.

9. Esthetic and Psychological Factors.

Hazards. - Hazards arise principally from traffic, fire, and explosion. Traffic hazards will be covered in a separate section. There are two types of community costs associated with fire and explosive hazards; fire losses in excess of insurance coverage plus increased insurance costs, and the cost of decreased density plus fire protection equipment needed to reduce fire losses.

The above types of hazard and their incompatibility costs decrease with distance from the hazard. Grouping similar hazards will reduce the incompatibility costs due to economies of scale in protection, in spite of increased damage potential of a conflagration.

Earth Vibrations. - Vibration effects are highly dependent on individual sites due to interaction with the soil and its stratification. Smith (1954) suggests liberal setback requirements for equipment which produces earth-shaking vibrations. Thus vibration might be classed entirely as a site adaptability cost, but note that two such adjacent installations may not require this same separation and thus it should be treated as an incompatibility cost. The principal application problem arises from the interaction of compatibility and adaptability. For instance, sound bedrock installations will have little vibration effect. However, vibrations are attenuated rapidly and are of concern only in allocation of uses to individual parcels, and thus may be disregarded in a macroscopic model such as that proposed herein.

Vibration measurement is not difficult, and although the equipment can be expensive, small communities could handle this by contract.

Noise.- Noise may be limited by performance standards to some specific number of units or to the average density of street traffic noise at the boundary. Noise commonly is measured in decibels, but the allowable maximum may be varied with both time of day and frequency (Sharpe, 1960). The allowable level is dependent on the adjacent use (American Society of Planning Officials, 1955) and thus an incompatibility cost is associated with differences in operating standards. Since noise is attenuated with distance, the cost will be a location factor, but again note that there is interaction with the particular site. Natural topography may be a barrier to transmission of noise, thus reducing incompatibility cost. Furthermore, noise transmission may be reduced by use of buffer space, trees (Sharpe, 1960), or earth berms (House and Home, 1967). Noise measurement is neither expensive nor difficult, but care must be exercised to measure at the appropriate time and location.

Odors and Gases. - Odors and gases may be undesirable due to noxious or toxic effects on plants and animals. Gases generally are limited by concentration according to type (Sharpe, 1960). Odors similarly are limited by concentration since in small quantities they may not be significant.

Since gases and odors disperse with distance, incompatibility will be a locational factor dependent on distance. In the case of odors, a difference in operating level will cause incompatibility. To reduce odor incompatibility cost, grouping may be desirable, but for gases the reverse is true since toxic gas concentrations build up and place a constraint on the grouping of gas-producing uses.

For some types of gases, measurement of concentrations is both difficult and expensive. Odor measurement, on the other hand, is a subjective

rating, and Sharpe (1960) stated that a group of disinterested persons could be successful in its evaluation.

Heat, Glare, and Lighting. - Glare and heat usually are limited by the requirement that operations which produce them be carried out within an enclosure. Exterior lighting, which otherwise would cross zone lines, may be controlled satisfactorily by screening, and should not produce serious problems.

In any case, all of the above are simple to measure. As in the case of noise, the nuisance of heat, glare, and light, although attenuated by distance, may be eliminated by interaction with natural topography and physical screening.

Dust and Smoke. - Dust and smoke controls consider the opaqueness of the resultant air (smoke) and the amount of particulate matter which may settle out (dust). Smoke density is measured generally by comparison of smoke to shades on the Ringelmann chart, one through five. Particle measurement is an expensive, complicated process, particularly when the dust arises from traffic or stone and aggregate operations, but also for ordinary stack emission (Sharpe, 1960). Both dust and smoke nuisances are correlated with local topography and wind conditions so that there is an adaptability-compatibility interaction here also.

Electrical Interference. - Electrical interference problems which are not of a community-wide nature are not common (Sharpe, 1960). Since they usually do not affect location, they will not be considered herein.

Traffic. - Traffic generated by activities has three harmful external effects; safety, noise, and fumes. Incompatibility of uses may arise when heavy volume roads are contiguous to or in the proximity of certain low operating level uses, particularly residences. In the case

of noise and fumes, the negative return increases as distances decrease, but safety is primarily a matter of detailed design rather than allocation.

Measurement of traffic by time is obtained simply as a volume, or preferably, volume by type. Time of the traffic may be particularly important for residential uses.

Esthetic and Psychological Factors. - These two factors are exceedingly difficult to evaluate. The compatibility return may be either negative or positive. Measurement can be made for psychological factors by an "opinion gradient" (Clark, 1948), and perhaps the same might be used for esthetics.

Although performance and operating standards may be criticized for difficulties in measurement and enforcement, these problems are being reduced by technology and experience respectively. They are, to date, the only means known to the author suitable for incorporation in an allocation programming process. Although they cannot be used to resolve all the problems associated with compatibility, it should be remembered that criticism of their defects, such as enforcement problems arising from industrial use process changes, are applicable to all other forms of zoning. In view of the continuing improvement in establishment of operating standards, these will be used in the program to be developed.

Community Goals: Their Evaluation and Application

Normative area use programs may be defined as the product of a planning process which directs the location of activities and the development of communications facilities to satisfy community goals. Descriptive area use models, on the other hand, have attempted to predict the

land use patterns so that public services may be programmed for the expected pattern. In the former case, the arrangement of both activities and communication is regarded as controllable, while in the latter, communications are designed to serve essentially fixed area uses.

The objective of the normative program is to optimize the satisfaction of community goals, and thus it implies the definition of these goals, and their evaluation.

Goals

Goals, as defined herein, are the state towards which the participant would like to move. It has been assumed above that a consensus of individual desires can be achieved to form community goals.

The only goals which are of concern herein are those which affect area use allocation. Further, there must be some choice and some possibility of realization of these goals, or they are irrelevant (Lynch and Rodwin, 1958). The relevant goals, insofar as possible, should then be placed into orthogonal components for model and programming procedures. The requirement that all goals which affect area use be considered implies that their evaluation should account for indirect effects on goals which have not been considered directly.

It is hypothesized that the effect of area use allocation on the satisfaction of community goals is a function of parcel adaptability, channel density (users per unit channel length), areal density, and organization, only. The effect of organization is included in transportation costs, both linkage and nodal, plus incompatibility costs. Accordingly, the following set of goals as developed by Schimpeler (1967) has been analyzed for the effects on area use. The results are shown in Table 5.

Table 5. Interaction Matrix of Goals and Area Use Allocation Factors.

Goal No.*	Area Use Allocation Factors				
	Adaptability	Channel Density	Areal Density	Transportation	Incompatibility
A-1	x#	x	x	x	x
A-2					
A-3	x	x	x	x	x
B-1	x	x	x	x	
B-2	x	x	x	x	
B-3	x	x	x	x	x
C-1				x	
C-2					x
C-3	x		x	x	x
C-4					
C-5	x	x	x	x	x
C-6	x	x	x	x	x
C-7				x	
D-1	x		x		x
D-2		x	x		
D-3					x
E					
F				x	
G-1					
G-2					
G-3					
G-4	x	x	x	x	x
H-1	x		x		x
H-2	x			x	x
I-1 to 7					
J-1	x				x
J-2					
J-3	x				x
J-4					

*Refer to Table 6.

#Interaction is denoted by x.

Table 6. Specific Statements of Community Objectives (Schimpeler 1967)

A. PUBLIC SAFETY PROGRAM DEVELOPMENT

1. Insure safe public facilities.

2. Provide for adequate public safety regulations and their enforcement.

3. Provide for the removal of contaminants (solid, liquid and gaseous).

B. PUBLIC UTILITY AND TRANSPORTATION DEVELOPMENT

1. Minimize maintenance costs of public facilities.

2. Insure maximum effectiveness of public utilities, by design and locational considerations.

3. Develop a balanced, effective and integrated transportation system which provides for the accessibility requirements of each land use.

C. ECONOMIC DEVELOPMENT PROGRAMS

1. Develop public improvement programs within available financial resources.

2. Maintain highest equitable property values.

3. Insure effective utilization of mineral, vegetation, air and water resources.

4. Establish a strong economic base through commerce that will bring money into the community.

5. Establish trade development that provides maximum convenience to consumers.

6. Insure the optimal utilization of all land.

7. Achieve increased disposable income for all people.

D. CULTURAL DEVELOPMENT

1. Preserve historic sites and areas of natural beauty.

2. Promote adequate public libraries, museums and cultural activities.

3. Protect meaningful local tradition and encourage civic pride.

Table 6. (continued)

E. HEALTH PROGRAM DEVELOPMENT

Establish the mechanism for adequate preventive and remedial health programs and facilities.

F. EDUCATION PROGRAM DEVELOPMENT

Develop educational facilities and opportunities for citizens at every level.

G. WELFARE PROGRAM DEVELOPMENT

1. Eliminate injustice based on discrimination.

2. Develop needed public welfare programs.

3. Encourage development of religious opportunities.

4. Develop an aesthetically pleasing environment.

H. RECREATION PROGRAM DEVELOPMENT

1. Establish open space programs.

2. Provide adequate recreational facilities utilizing parks, rivers and lakes.

I. POLITICAL FRAMEWORK

1. Improve the framework (channels, systematic use) for citizen participation in governmental functions.

2. Establish equitable taxation policies (bases, mixes, rates).

3. Achieve efficient governmental administration, representative of all citizens.

4. Develop adequate government staffs and personnel programs (high job standards, reasonable salary ranges, effective delegation of authority).

5. Establish sound governmental fiscal programs.

6. Develop an effective, long-range, metropolitan-wide, planning process.

7. Establish effective control mechanisms.

Table 6. (continued)

J. HOUSING DEVELOPMENT

1. Encourage rehabilitation and conservation neighborhood programs.

2. Provide adequate low cost housing.

3. Develop neighborhood units.

4. Promote a wide variety of housing types as required within the community.

Evaluation and Application

Since the evaluation of goals is the subject of a recent thesis (Schimpeler, 1967), this general area will be reviewed only briefly and examined for specific application in an area use program.

Evaluation of an urban system implies the assignment of utility values to both inputs and outputs of the system. Money and time are inputs, whereas goods and safety could be outputs. The utility added by a given policy then will be a measure of the value of the plan. Ackoff (1962) notes that cost per unit of urban service generally has been used to evaluate services because of the difficulty of obtaining a common scale. But, as he points out, the unit cost procedure permits only comparisons within subsets of the universal choice set, whereas the utility added method permits comparison between any two pairs from the universal choice set, that is, whether any one alternative is "good enough" (Ackoff, 1962 p.95). In some societies, minimization of cost rather than maximization of utility added may be the major goal, but this is a special case of the utility added method.

Ackoff (1962, p.95) prescribed the following steps to develop a utility measure of a solution:

1. Identify the individuals and collectives . . . which are involved in the activity under study.

2. Identify those preservative and acquisitive objectives of the participants which are affected by the relevant activity.

3. Identify the inputs and outputs associated with the relevant objectives. . . .

4. Provide an operational definition of each relevant input and output and specify how these are to be measured and what scales are to be employed.

5. If more than one scale is specified in step four, select one of

these into which the others are to be transformed and call this the "effectiveness scale". . . .

6. Find the utility function of the effectiveness scale.

The last step accounts for change in utility of units as the number of units changes.

One of the effects neglected by this procedure is the interdependence of activities. If two activities are to be considered, their interaction may affect both the input and output utilities of the system. If one activity already exists, however, both the utility of the main effect of the new activity and its interaction with the existing activity may be assigned to the new activity insofar as the decision to initiate this new activity is concerned.

An important assumption which the method requires is that the utility of one individual may be added to that of another. Arrow (1963) contended that such an addition is not feasible, but Ackoff (1962) does not accept this view. The latter's position implies that rational social decisions are feasible (that is, decisions which will maximize aggregate expected socio-economic utility) and it is from this premise that the model is developed herein.

The participants involved in the area use model are the residents of the area. The collective organizations in the area and the operators of the communications systems are considered insofar as their activities are reflected in the costs and benefits accruing to the residents.

The objectives of the public with respect to communications were classified by Ackoff (1962) as follows:

1. Minimize cost.
2. Minimize lost time.

3. Minimize harm.

4. Minimize lost energy.

5. Maximize enjoyment.

Most writers (Haig, 1927; Carroll, 1949; Webber, 1963a) have concentrated on the minimization of friction of space to ease human interaction. Ackoff's five objectives are components of this space friction minimization. But, site adaptability also influences area use allocation, even though it is not a communications factor. Thus minimization of adaptability costs could be a sixth objective. Finally, the fifth objective might be expanded to represent the maximization of return or output of the total system.

Conversion of all the objective scales into one common scale is not an easy matter. However, one unit of any objective can be converted to the maximum amount of money that a person will pay for it. This yields a distribution of values based on each person's characteristics, including income. Considering safety for instance, Ackoff (1962) suggests that a value on life can be obtained by the amount an individual will pay to reduce the probability of death by some fraction. This value scale likely will not be proportional to the death probability, but this can be compensated for by the dollar-utility transform.

A detailed discussion and a report of research into utility values of community goals is given by Schimpeler (1967).

Assuming that an objective function may be set up to optimize area use allocation according to the above objectives for a given time, the extension to the dynamic case presents the next problem. Since planning can be based only on predicted conditions, then planning decisions must take into account the predictions and the associated probability of

occurrence. Further, the value of flexibility should be accounted for, and thus an additional factor is added to the optimization procedure.

Whether or not such an optimization procedure will prove useful is dependent on the planner's ability to identify and predict the level of the independent variables of the problem, and their functional relationships. Leven (1964) regarded a planning model as a means of optimizing a function of a dependent variable(s) which is (are) in turn a function(s) of independent variables. The latter are constrained to some feasible region and may or may not be controllable. If the independent variables are not controllable, then the normative program results cannot be applied. Even if they are controllable, the question of whether one can predict the relationships of the dependent and independent variables accurately must still be asked. If not, then the procedure, though valid, is not practical until such time as the predictions can be improved.

Sensitivity of Costs and Returns to Density and Organization

Since some community goals may be expressed in terms of density and organization, and these factors are controllable, a normative program must evaluate the inputs and outputs associated with density and organization in order to determine the optimum plan. In the following discussion, some cost data are presented for the purpose of showing the relative importance of various costs and returns associated with density and organization. Since the model is formulated in terms of variables and parameters which the user must determine for each application, no attempt is made to obtain precise values for these costs and returns. In fact, these will vary from case to case, and over time.

Hawley (1951) has shown a high correlation of population and housing density to government costs per capita. Unfortunately, it is difficult to determine the true sensitivity of costs to density or organization since they generally are correlated to each other as well as to total population size. In addition, the return varies considerably, complicating comparisons of both practical cases and design models. Available cost data by function often take into account only public expenditures, deleting other private and public costs. Since private costs of utilities etcetera are borne ultimately by the public, Pardee (1966) notes that the planning objective should be to minimize ultimate development and operational costs. To temper this, it should be remembered that individual choice is a public benefit and should be included in the analysis. The costs to be considered herein are only those due to interaction; that is, the returns from the main effects may be deleted since they are independent of both absolute and relative location in space.

Considering a potentially separable activity it may be shown that this activity has an economy of scale. If the economy exceeds the communication costs incurred by separation from its parent institutions, then separation will occur. This process occurs throughout the urban hierarchy, and each activity seeks a level at which the scale economy balances the communication costs. The scale economies are dependent on the population served, but communication costs are dependent also on the organization and density of that population.

Vehicular transportation is the most important communication cost in an urban area. It comprised 24.5 percent of the gross national product and 12.6 percent of personal consumption expenditures in 1963

(Bureau of Census, 1965). Of the latter, proportional distribution on a mileage basis between urban and rural travel (Automobile Manufacturers Association, 1966) indicates that approximately 50 percent or 175 dollars per capita is expended annually on urban travel. This, of course, does not include time costs. In addition, local governments spent more in 1963 on highways than on any other service except education (Bureau of Census, 1966). This local expenditure amounted to approximately 20 dollars per capita, with approximately 50 percent each to capital and non-capital costs (Bureau of Census, 1965). The annual expenditure on urban transportation (excluding industry costs) then is approximately 195 dollars per capita, plus state and federal expenditures in urban areas.

The cost of travel time is controversial, but it is undoubtedly an important factor in transportation. American Association of State Highway Officials (1960) recommended 0.86 dollars per hour per person. This figure was criticized by Mohring and Harwitz (1962) as being unreasonably low, but nevertheless it can be regarded as an initial conservative estimate. Smith and Associates (1966) found average mean trip time to vary from 8 minutes in cities of population less than 100,000 up to 30 minutes for cities whose population exceeds 5,000,000. Levinson and Wynn (1962) found that the average number of trips varies from 1.6 to 2.5 per day. Using a very conservative basis of 8 minutes per trip, 2.0 trips per day, for 200 week days, at 0.86 dollars per hour, the annual time cost per capita is 46 dollars. In the large cities it would be at least 173 dollars per capita, using the same conservative basis with the average trip time equal to 30 minutes.

Ackoff (1962) points out, however, that only lost time should be

considered in evaluating transportation time costs. He suggests that time be valued on the larger of; loss in value to the community, or the person's own value of his time. This could be determined from the maximum price he would pay for a faster means of travel. Thus a rational basis for determining the effect of both time and material resource costs appears to be feasible. Chapin and Hightower (1965) hypothesized that people tend towards indifference to time value below ¼ to ½ hour trips, depending on the city size. However, it seems likely that this indifference may reflect a feeling that no better alternative exists rather than indicating that no utility is assigned to that time.

Public utilities also constitute a major communication cost, primarily as a channel cost. Thus the per capita cost of utilities is dependent on the number of users per unit channel length (channel density).

Sanitary sewerage costs are dependent on channel density, but storm sewerage costs are dependent on both channel and areal density since the amount of run-off is a function of type and amount of land uses. Capital outlay for sewerage and sewage treatment in 1962 amounted to 4.77 dollars per capita (Bureau of Census, 1963). Isard and Coughlin (1957) assumed that approximately 90 and 75 percent of this capital would be required for sewerage in "medium and high density" residential areas, respectively, in a large metropolitan area. They found that over a 20 year period, a gridiron street pattern development at 4 dwelling units per acre required 4 times as much capital for sanitary sewers and 2.75 times as much for storm sewers as a similar development at 16 dwelling units per acre. Since the majority of the public capital invested in sewage collection and treatment is required for the sewerage system, the effect of density is very important. With regard to operational costs of the sewerage

system. Steel (1953) found an average of 0.375 dollars per capita per year at the time of his study, and thus this item may be neglected.

Water supply costs, like sewerage costs, are highly dependent on channel density. In 1962 (Bureau of Census, 1963), per capita costs for water were 11.58 dollars. Howson (1956) notes that approximately 50 to 70 percent of such costs are expended on operation and maintenance. Of the capital costs, Steel (1953) found that approximately 75 percent goes to pumping stations, reservoirs, and the distribution system itself. All of these components are for distribution, and their costs are dependent on channel and areal density. Areal density has an effect on costs of water systems, due to fire flow requirements and the desirability of alternate routes in a pressurized system.

Electric utility revenue for residential areas is approximately 3 times as large as water revenue (Howson, 1956). Both power and water systems are pressurized, and unlike the strictly hierarchical sewerage and telephone systems, costs depend on both channel and areal densities. Power distribution costs amounted to 15.1 percent of the total cost in 1964, and they depend primarily on channel density. Although no figures on cost sensitivity to density could be obtained, it would seem likely that rate reductions have been prevented by sprawl.

In 1961, gas revenues amounted to 147.58 dollars per customer, of which 6.7 percent or approximately 10 dollars was expended on distribution costs (American Gas Association, 1961). Schecter (1961) notes that distribution costs are rising. Gas-main mileage rose 23 percent for a 14 percent increase in number of customers. This is attributed to the servicing of lower density areas.

Telephone service costs are dependent primarily on the size of the exchange. Meyer (1962) found that investment per subscriber in outside exchange plant of the Richmond District of the Chesapeake and Ohio Telephone Company amounted to 285.11 dollars on December 31, 1960. Disregarding the exchange and outside operation and maintenance costs, the above cost of capital may still significantly affect overall cost - density sensitivity.

Urban postal delivery service requires approximately 6.50 dollars per capita (Bureau of Census, 1965). This will be affected by channel density, but certainly not in direct proportion.

Police and fire protection costs, both of which are dependent on space and channel density, cost 10.24 and 6.37 dollars respectively in urban areas in 1962 (Bureau of Census, 1965).

The cost to the public of education was the greatest governmental expense at 100.07 dollars in 1962. In addition, education requires substantial travel time. Isard and Coughlin (1956), considering only the governmental expenses, found that for schools of less than 400 to 600 pupils, per capita costs were considerably higher, and level of service lower, than for large schools. Of course these larger schools result in higher travel costs, but the time value involved is low.

Air pollution costs and returns, arising from health, comfort, and esthetic causes, are more difficult to evaluate. Faith (1959) estimated annual United States economic costs due to air pollution at 250 million dollars. The total air pollution cost, including negative returns of comfort and esthetics, is an important density effect, but local variations due to specialized industry are large. Costs are dependent primarily on population size and density, the types of specialized

activities, and local populati n characteristics.

Refuse collection costs a affected by both d ity and city size (American Public Works Associat n, 1958). However, these effects may not be important since average s itation costs other than sewerage were only 3.83 dollars per capita in 1962 (Bureau of Census, 1962), and much of this cost is independent of normal variation in urban form. McCallum (1956) assumed garbage collection costs to be independent of density.

Turning from the costs of building and using urban facilities to the returns, these benefits fall into the classes of esthetics, space preference, sociability, and privacy.

Esthetics have come to the public's attention recently as an important criterion in planning in the United States. In most applications, esthetic benefits are derived from design details which are at too fine a scale to be considered in an area use program. In some cases they will affect adaptability costs of a given use to a given area.

Space preference is a vitally important factor in design. Meier (1962) stated that man, like other animals, requires a minimum amount of space to sustain life. Ardrey (1966) and Lorenz (1963) have shown further that the territorial instinct in fact causes any animal, including man, to lose his inhibitions when he is too closely confined, resulting in intraspecific aggression. Schmitt's (1966) results showing positive correlation of density of population and crime rates may well be due at least partly, to this phenomenon. Thus when space preference is largely unsatisfied, the social and resultant economic loss in benefit may be large. Space preference benefits probably should be expressed in terms of both areal density and channel density. These factors will be considered in the following section on adaptability of a location to a use.

Social benefit has not been studied in quantitative terms and has not been related to urban form to any great extent. Analysis of economic resources that a given population stratum will forgo to obtain a desirable social pattern is one potential scale for social benefit measurement. This benefit will be affected by both density and organization. Time allocation to social activities has been used by Meier (1962) as a scale for urbanity, suggesting another approach to measuring the social benefit of an urban form. Unfortunately, the social pattern as well as social values are changing very rapidly as a result of technological change, particularly changes in mobility and communications, so that any such analysis is exceedingly complex. Its results can be specific only to a time period of a specific culture and class. Duhl (1963) highlights the difference in class values in his analysis of urban renewal of a slum area which resulted in detriment to the community. The program resulted in a loss because it was deemed justifiable and was initiated by a group whose social values differed from those of the slum dwellers, and although physical conditions "improved", it was at the expense of more precious social organization. Gans (1961) feels that the planner should provide choice but not promote any one social pattern.

Privacy is the ability to prevent "communications overload" (Meier, 1962. p.81) by rejection of messages. It tends to be in opposition to sociability, but the capacity for privacy when desired does not necessarily exclude sociability. This can be satisfied by accessibility to social intercourse when desired. Willmott and Cooney (1963) found sociability and privacy benefits to be opposed in some housing types. Large multi-story apartment blocks afforded the greatest privacy and the least sociability. Short blocks and cul-de-sacs tended to be more sociable

than long blocks. However, as with sociability benefits, there was no attempt made to analyze the problem in quantitative terms. Privacy is included in design at the detailed level of organization (Chermayeff and Alexander, 1963) rather than town planning, and thus would not be included in normative design at the metropolis scale.

Adaptability

The location of activities is due primarily to the cost of communications (Isard, 1956). However, communications are not the only criteria.

The need to review area use locational and growth factors in terms of adaptability and communications requires separation of parcel characteristics into orthogonal components; those associated with specific parcels irrespective of other uses, and those associated with land solely because of proximate uses. It is obvious that the two categories will have different roles in growth and location and thus should be incorporated differently in an allocation model.

If a hypothetical activity has no communication with the outside world the only factor in choice of land is the cost of adapting the land parcel to the given area use. One factor which could be considered is the cost of water supply development for the land. This is partially a fixed factor associated with the land parcel, termed adaptability but it may be affected also by external economy of scale if water is needed by several nearby land parcels. The latter is assumed to be a communication factor which is associated with relative location rather than absolute location, as in the case of adaptability.

The basic characteristics of a land use parcel are: plan, topography, soil and/or mantle composition, flora, fauna, fluids and existing

structures and facilities. Lynch (1962) also notes the importance of history or sacredness in some cases, but this is a special case of existing structures and facilities.

The plan of a parcel may be a deciding factor in potential use. For instance, Gruen et al. (1960) note that size and shape of the parcel(s) are important factors in shopping center location. This is true also for many industrial uses. However, this is a detailed consideration not generally of concern at the macroscopic level.

Chapin (1965) states that an important topographic location factor, slope, is partially dependent on the geographic area, noting that in San Francisco slope is not the deterrent to development that it is elsewhere. This is really a case of supply and demand and indicates that for a given area we may be more interested in differential than absolute values. A second topographic feature is elevation with respect to surrounding areas. In other words, the general slope of the community has a different effect than the local slope. A parcel with steep local slopes may be subject to flooding and have little view of the surrounding areas, whereas some flat parcels may be the reverse if they are located on an escarpment.

Soil and mantle composition may be important as potential foundation materials or as mineral resources.

Flora and fauna are of concern from the esthetic and recreational viewpoint, and may preclude all other use (Michael, 1966). From the safety aspect, Lewis (1949) points out that Boston eliminated a health hazard due to fauna by filling tidal flats and using this land as parks. Fluids are causing increasing concern with respect to pollution. In the case of air pollution, the causes may be principally local, and thus may

be treated as a communications factor under compatibility. However, water pollution may originate non-locally and thus be ubiquitous. Drainage is difficult to treat. The land has certain drainage characteristics, both topographical and compositional, but the amount and intensity of runoff may be affected by both local and non-local development. Thus drainage could conceivably appear as both an adaptability and a communication factor.

Cultural features are sometimes difficult to incorporate in a model. Existing structures may be demolished for redevelopment, rehabilitated to certain standards for the same or similar use, or conserved in their existing state (Chapin, 1965). Each of these factors could be assigned an adaptability cost for a given use. Consider, however, an existing water supply system which has an excess capacity. This excess capacity might be used at any point over some large area. It can be considered an inherent advantage for that area, but how is it distributed within the area? If, for instance, high density development requires new supplies above the existing excess, the assignment of costs to areas within the water area becomes one of judgement.

Religious, and particularly historical areas, may have to be preserved at any cost. Thus their effective adaptability cost for any other use is infinite. Disruption costs in the change of land uses are another important adaptability cost. Both of these factors may be aggregated with cultural facilities.

In view of Alonso's (1964) conclusion that more and more industries are becoming "foot-loose", environment and thus adaptability of land parcels will become increasingly important relative to communication.

On the national scale, Spiegelman (1964) showed that environment is of primary importance to location of non cost-sensitive industry. This principle should apply equally well at the community level.

Optimum Community Size

The scale economies associated with various hierarchy levels versus the diseconomies of scale, particularly communication costs, suggest that for given community goals there may be an optimum community size for each location. This question of optimality of city size is one of the oldest in planning. Plato (Gallion and Eisner, 1963) suggested that a population of 5,000 to 10,000 was best for the polis. Reiner (1962) provided an extensive list of "optima" which various planners have suggested, ranging as high as 8,000,000 for the Goodman brothers' City of Efficient Consumption (a paradigm). There are two factors, in addition to the physical environment, which alter the optima; the relative weights of goals, and the change of weight over time. For instance, the relative weight of efficiency in consumption of material goods for the paradigm given above was infinity. Even so, this factor is correlated to others, particularly transport, and as it changes over time, so does the optimum. It is evident that an optimum satisfying all persons is not feasible for the static case, and even a welfare solution for the real dynamic case may be impractical.

Hauser (1965) notes that the areal extent of a city was at one time limited by factors such as walking distance and the distance that water could be carried. He also notes that archaeological evidence suggests that densities may have reached as high as 128,000 per square mile and thus limited population size because of health conditions. With

advances in both transport and sanitation, individual urban areas have increased drastically. Even so, in 1955 Ratcliff suggested that the central retail area is still limited by walking distance, and this is true also for outlying shopping centers. Whether this will remain true for long, with improved transport, is another question.

The key factor then for city size may well be transport, since it has been shown to be important to both the location and growth of the urban area.

In a preceding section, the relationship of city dominance and size to city functions was stressed. Baumol (1962) pointed out that there are both economies and diseconomies of population scale. At a certain level of market size, an economic function becomes profitable. As the market or population size increases, so do the number of economic functions which are practical, due to economies of scale. On an empirical basis, Duncan et al. (1960) found that cities have a critical population size with respect to a given function, above which at least one unit of that function is present. However, there are also diseconomies of scale. Transport and other forms of communication become increasingly complex as size increases. If all the nodes in an urban area are linked directly, for the n^{th} node added there will be n-1 links added. However, even for the practical transportation network which may approach the hierarchical system, the linkages become exceedingly complex. Silver (1959) found that for a 31 percent increase in Washington's population between 1948 and 1955, there was a 71 percent increase in travel. Voorhees et al. (1962) found that logical grouping of trips could reduce travel considerably, but above a 200,000 population level of each subregion average trip length increases substantially. Figure 7 shows that

at approximately this population, public expenditures on highways also reach a minimum, but the variation in level of service is unknown. One advantage of the larger city size is that the freedom of choice of mode increases. Also, mass transit systems become economically feasible.

It may be seen from Figure 7 that sewerage, fire protection, and police protection costs increase with total size of population. Education costs are minimized at a population level of approximately 300,000 but this does not account for the level of service. Welfare and health costs tend to increase with population increase. Undoubtedly, part of these latter incremental costs arise from a load imposed on the higher level cities by hinterland residents or migrants from the hinterland, but probably not all. Bowers and Lovejoy (1965) found that telephone service costs are substantially constant at 70 dollars per year for an exchange of up to 50,000 lines, but this cost progressively increases reaching 90 dollars at 300,000 lines.

The value of access to specialized and differentiated social and other economic functions changes rapidly with size, but unlike the preceeding, most evaluation is an individual matter. In the aggregate there will be both advantages and disadvantages.

It might seem, then, that for a given system, a balance between economies and diseconomies of scale could define an optimal size. However, the community must first evaluate its community goals so that the oft-conflicting goals may be placed on one scale. Suffice it to say that undoubtedly there is no one optimum size for all cities, nor is the optimum for a given city static.

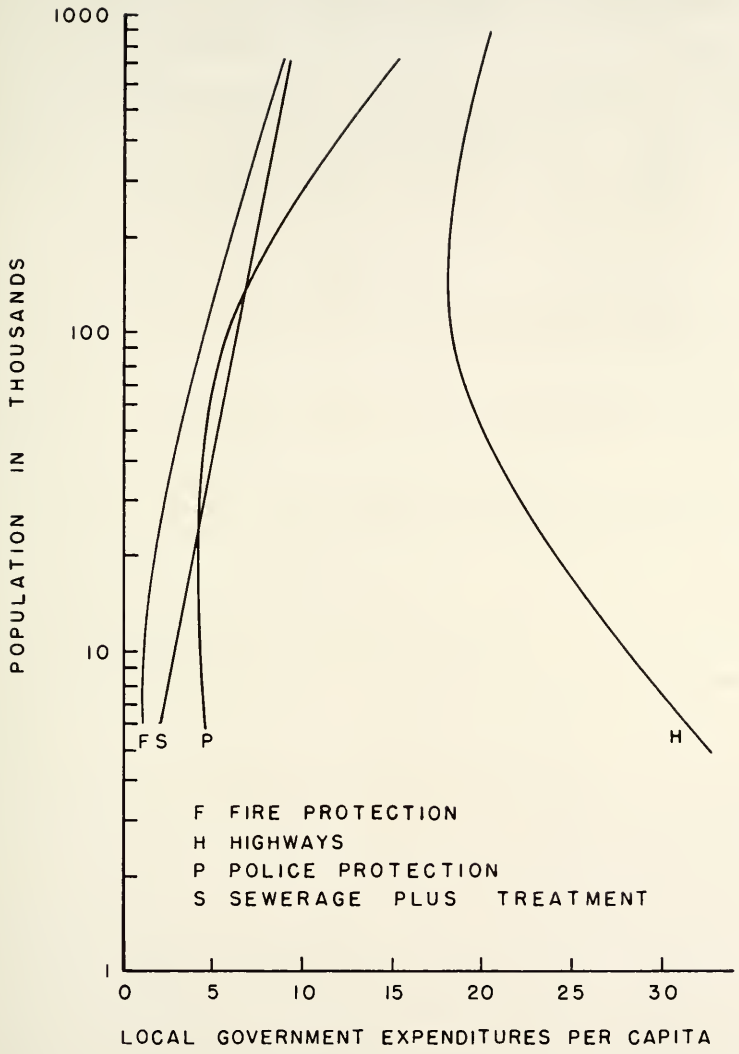


FIGURE 7. SOME LOCAL GOVERNMENT EXPENDITURES VERSUS POPULATION SIZE

Discussion and Summary

It has been shown that throughout the evolution of metropolitan communities, transport has been the key factor in the location of population, the separation of activities, and the growth of urban areas. Differential characteristics of individual sites and forms of communications other than transport, particularly by-product transmission, also have had significant effects on both location and growth.

In order to examine the relative importance or costs of transport, by-product transmission or incompatibility, and site adaptability, the form and structure of urban areas have been analyzed. From this analysis, density and focal organization have emerged as the major locational variables in the arrangement of separated land uses. The grain of the community generally is not sensitive to cost, and may be determined by local design. The density of an urban area is determined principally by an economic balance of transport cost and space preference or needs. The focal organization is determined by a balance of scale economies and inter-activity transport costs. Thus it is not surprising that sensitivity of costs and returns is dependent primarily on transport. Because of this primary dependence, generation of communications today and potential changes in that generation have been examined in detail.

The principal conclusion of this review is that a normative area use model should consider transport and inter-use incompatibility costs, differences in site adaptability for area use allocation, and economies of scale in the allocation of activities to given sites. But, in order for such a model to be practical, the determination of community goals which are affected by location. and their evaluation in terms of a common unit must be feasible.

THE URBAN MODEL AND ITS NORMATIVE OBJECTIVE

The Model

An urban structure has been shown to be a group of activities linked by communications. The latter can be divided into two classes, the desired flows and the undesirable by-products of both the activities and the flows.

An urban form which accommodates this structure can be represented by a group of locations, a network of channels linking the location centroids, and barriers between each pair of locations. It is implied that each location should be delineated so that it is homogeneous with respect to local and general slopes, flora (natural cover) and fauna, foundation materials, water conditions, cultural facilities, and access to the centroid and thence the channel network. If these characteristics can be assumed to be similar within the location, then average values for each characteristic can be used in the model.

Barriers to inter-location by-product transmission are assumed to exist between all pairs of locations, but for proximate locations their effectiveness tends to approach zero. That is, the fraction of by-products transmitted through the barrier tends to approach one. Conversely, a pair of locations separated by one or more intervening locations (one form of barrier) has only a small amount of by-product transmission and the transmission value approaches zero.

The flow channels available for the movement of the generated flows

include, but are not necessarily restricted to, channels in the plan area. In most cases, the flow channels would consist of major and minor arterials and collector streets. Any transport route outside the plan area should be included in the plan area model if the unit flow cost between any two locations is less by that external route than by the minimum path route via internal channels. That is, the channel network should be convex in the flow cost space. For an example of such a communication node located outside the plan area, refer to node 514 in Figure C2.

Where there are large numbers of locations involved, it may be necessary to simplify the computations on long distance flow costs. This can be achieved by aggregating locations with similar major thoroughfare access, to form districts. Flows then may be treated in two groups, those whose destination lies within the district containing the origin location and those whose destination lies in another district. The first group of flows is assumed to originate and end at the appropriate location centroids, whereas the second group of flows is assumed to originate and end at the appropriate district centroids.

The functional relationships between these model factors can now be expressed more precisely under the following categories:

1. Required activities and uses.
2. Locations and use allocations.
3. Flows.
4. By-product transmission.

Required Activities and Uses

The number of units of each activity which will take place within the area is a function of the local population strata characteristics,

local natural and cultural resources, and the extramural interactions with the surrounding region and with urban realms. In a general model the amounts of each activity could be variables whose levels are determined by the solution of the model. But, in the model developed herein, the amounts of each activity are fixed as model inputs. These amounts can be estimated or predicted from population and economic surveys.

Although the units of a given activity may be treated as fixed, the activity may be accommodated by several area uses. An individual use is characterized by both the type and density of the activity. For example, the residential activity for one type of family could be satisfied at the following density levels:

1. Apartments (high density residential use).
2. Town-houses (medium density residential use).
3. One-family residences (low density residential use).

Similarly, an industrial activity may be accommodated in a single story structure or in a multi-story structure, resulting in two potential uses for the same type of activity.

It may be seen that the given data for a model must include not only the number of units of each activity, but also the number of units of an activity which will be accommodated by each use. Further, the uses and activities must satisfy the following:

$$1.1 \qquad \sum_{K \in S_T} \sum_{I=1}^{N} Y_{TK} \cdot X_{IK} = A_T \quad \text{for every } T,$$

where: $\in$ denotes "an element of the set of"

S_T = the set of uses which can accommodate activity T

N = the number of locations in the plan area

Y_{TK} = the number of units of activity T per acre of use K

X_{IK} = the number of acres of use K allocated to location I

A_T = the number of units of activity T.

Locations and Use Allocations

The plan area has been represented as a group of locations, each having a finite area and homogeneous characteristics. The area of each location is fixed. Since all of that area must be assigned to one or more uses (one of which may be the vacant use), the use allocations must satisfy the following:

1.2 $$\sum_{K=1}^{M} X_{IK} = P_I \quad \text{for every I,}$$

where: X_{IK} = the number of acres of use K allocated to location I

M = the number of uses

P_I = the size in acres of location I.

The use allocations must be non-negative and thus satisfy the following:

1.3 $$X_{IK} \geq 0 \quad \text{for every pair of I and K.}$$

Flows

Flow costs have been shown to be due primarily to person trips. Accordingly, to simplify the model, other significant flows could be expressed in terms of person trips. The total of all types of flows then could be represented as equivalent person trips. To simulate flow costs more precisely, however, some types of trips might be weighted according to their peaking or time density characteristics.

Total flows are input to the model as the number of equivalent person trips generated per acre of origin use. Each use will have

associated trip generation rates, one for each trip purpose as defined by the destination use. Ideally, these rates should be dependent on the trip cost (Grecco and Breuning, 1963). However, until the results of research into these relationships becomes available, the model has to assume that these rates are fixed. Further, it has been assumed that trip attractions are balanced by trip productions and are distributed uniformly over all acceptable destination use allocations. That is, trip ends must satisfy the following conditions:

1.4 $O_{IKL} = Z_{KL} \cdot X_{IK}$ for every combination of I, K and L

= equivalent person trip origins of type KL (that is, originating at use K and destined to use L) generated by location I,

where: Z_{KL} = equivalent person trips of type KL generated per acre of use K

X_{IK} = the number of acres of use K allocated to location I.

1.5 $$D_{JKL} = \sum_{I=1}^{N} O_{IKL} \cdot \frac{X_{JL}}{\sum_{H=1}^{N} X_{HL}}$$ for every combination of J, K and L

= equivalent person trip destinations of type KL attracted to location J

where: X_{HL} = the number of acres of use L allocated to location H

X_{JL} = the number of acres of use L allocated to location J

N = the number of locations.

One last model constraint must be placed on the flows. Namely, the choice of flow route is made according to the economic welfare norm. That is, the flow route choices are made such that the total flow cost of the entire community is minimized. Thus the flow routes are fixed for a given allocation of uses and a given transportation system.

By-product Transmission

Incompatibility of use allocations occurs only if the harmful by-products are transmitted. Between all pairs of uses there are spatial and/or physical barriers to such transmission. It has been assumed for model purposes, that these barriers modify the standard (unrestricted) by-product transmission rate between two adjacent locations of average size, as follows:

1. The transmission values are proportional to the ratio of the given interface length to a standard interface length determined for each model application.

2. The transmission values are reduced by some factor if there is an intervening use.

3. The transmission values are reduced by some factor if there is a physical barrier to transmission.

In the general case the transmission rate will not be the same for each by-product. For example, earth embankments may be effective as noise barriers but not as odor barriers. However, until further research has been conducted into incompatibility, it was deemed advisable to assume a single transmission rate for all by-products.

The Model Norm

The model presented above includes the necessary constraints on the set of feasible area use allocations. But it does not describe the driving forces which lead to the selection of an element from that set. These forces are components of the community goals which are affected by area use allocation, and may be represented by location returns, adaptability costs, flow costs, incompatibility costs, and savings due to economies of scale.

Location Returns Less Adaptability Costs

Based on the literature reviews on adaptability of uses to locations and on sensitivity of costs and returns to density and organization, it was hypothesized that a net location return (location return less adaptability costs) could be expressed as follows:

$$2.1 \quad R_{IK} = K_{1K} + K_{2K} \cdot Cd^{-1} + K_{3K} \cdot Ad^{-1} + f_{4K}(T_I) + f_{5K}(F_I) + f_{6K}(D_I) + f_{7K}(N_I) + f_{8K}(S_I)$$

where: K denotes the K^{th} use, K = 1,....M

I denotes the I^{th} location, I = 1,....N

R_{IK} = the net location return for use K in location I

K_{JK} = a constant for use K, J = 1, 2, 3

$f_{JK}(\ )$ = a non-linear function of the bracketed variable, J = 4,...8

Cd = channel density

Ad = areal density

T_I = the topography rating of location I

F_I = the foundation rating of location I

D_I = the drainage rating of location I

N_I = the natural resources (excluding man-made) of location I

S_I = the cultural resources of location I.

The first three terms on the right side of the equation are of no concern if the amount of each use is fixed, since they are constant (not a function of I) for a given use irrespective of location.

Each component of the adaptability costs (the remaining five terms) is relatively constant throughout a location, except for the cultural or man-made facilities. When there are existing structures or other facilities on part of a location, there will be a very large saving in adaptation costs if the existing use is reallocated back to that part of

the location and thus to the existing structures. Consequently, two different net location returns will be calculated for each use in each location. The net return value which includes a zero cultural feature cost is applicable only when a use is reallocated to a currently existing use. It will be designated as R_{IK}'. In the other net location return, R_{IK}'', there will be a non-zero cultural feature cost which should cover the cost of demolition and dislocation of the existing activity as well as the cost of construction of new facilities. In practice, however, it is more expedient to add the demolition and dislocation costs as returns in R_{IK}' and neglect them in R_{IK}''. If this were not done, a separate R_{IK}'' would have to be calculated for each existing use. This expediency results in constant terms being added to the objective function, but the relative values of the returns are correct, and thus the allocations are not affected.

The two net location returns are necessary input data. They are independent of the allocation of uses.

Channel Flow Costs

The total cost of flow on a channel link may be composed of the following:

1. Channel capital cost.
2. Channel operation and maintenance costs.
3. Vehicular capital costs.
4. Vehicular operation and maintenance costs.
5. Time costs.

Note that several of these components are at least partially fixed, that is, independent of flow volumes. Furthermore, they are also independent of the area use allocations. Thus the channel costs will be split into;

fixed costs, which need not be considered directly in the allocation process, and the flow costs which are assumed to be related linearly to flows and thus must be considered in the allocation process.

Some of the flow cost components, and in particular the time costs, vary with the trip type. For example, time used for a shopping trip would be evaluated differently from the time used on a business trip. Thus it would be preferable to represent flow costs by individual values for each flow type. However, for simplicity, the flow costs for all trip types are assumed to be equal.

The unit flow costs which are input to the model are user costs for flows from district centroid to district centroid or location centroid to location centroid. These are determined by summing the flow costs of the channel links which comprise the least cost route. Note that the flow cost from location I to location J may differ from the converse due to one-way streets, restricted turns, et cetera.

It has been assumed also that the channel flow costs are independent of the flow volumes. This implies that there are no capacity limits on any route, unless the flow costs are set sufficiently high to limit volumes.

Inter-use Incompatibility

In the review of operating and performance standards, it was noted that positive incompatibility costs will result from differential operating standards.

It has been assumed that the positive incompatibility cost is:

1. Proportional to the difference in operating standards of the incompatible uses.

2. Proportional to the length of the interface where the incompatibility occurs.

3. Reduced by barriers such as major transport routes, topographical barriers, et cetera.

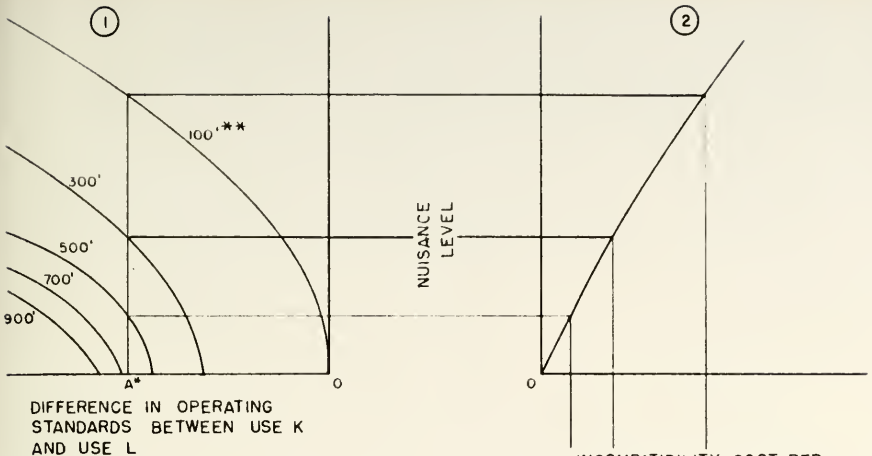
4. Reduced by spatial separation of the incompatible uses.

The utility cost of incompatibility at a given distance might be determined from what the user will pay to increase the distance of separation from, or to reduce the operating level of, the offensive use. By summing the cost distance curve over a typical location and dividing by area, a linear unit cost figure may be obtained.

An example of a possible procedure is given in Figure 8, using hypothetical values. The figure is based on the assumption that the incompatibility cost of use L to use K in adjacent locations may be determined by using average values for successive bands of 200 feet in width. As an illustration, the area of use L within the bands around use K was set at 65, 80, and 95 acres, for 0 to 200, 200 to 400, and 400 to 600 feet respectively. The difference in operating standards of use K and use L was designated as A. By entering graph 1 at A, the differential nuisance level and the unit utility cost for each band at its median separation distance from use K, were determined from 1 and 2 respectively. Then by utilizing the area of each band the total incompatibility cost for each band was determined from 3. The aggregate of these band costs was then divided by the total area to derive a unit cost for the two locations. This procedure may be applied to two average locations for any by-product under the assumptions that all of one location is occupied by use K and all of the other location by use L.

Assuming that there are P significant by-products, incompatibility costs may be expressed as follows:

$$2.2 \qquad In_{IK} = \sum_{J=1}^{N} \sum_{L=1}^{M} \sum_{Q=1}^{P} f_{KLQ} \, (O_{KQ} - O_{LQ}) \, G_{IJQ}$$



DIFFERENCE IN OPERATING STANDARDS BETWEEN USE K AND USE L

*ASSUMED LEVEL FOR EXAMPLE

**AVERAGE DISTANCE OF SEPARATION OF USES

TOTAL INCOMPATIBILITY COST DUE TO BY-PRODUCT Q

$10 + 15 + 25 = 50$

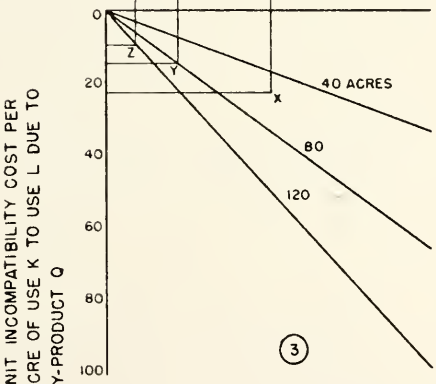
TOTAL ACREAGE

$65 + 80 + 95 = 240$

AVERAGE UNIT INCOMPATIBILITY COST (b_{KL})

$$\frac{50}{240} = .21$$

INCOMPATIBILITY COST PER ACRE OF USE K PER ACRE OF USE L DUE TO BY-PRODUCT Q



X = 65 ACRES OF USE L WITHIN 200' OF USE K

Y = 80 ACRES OF USE L BETWEEN 200' TO 400' OF USE K

Z = 95 ACRES OF USE L BETWEEN 400' TO 600' OF USE K

FIGURE 8 DETERMINATION OF THE COST OF INCOMPATIBILITY BETWEEN ONE ACRE OF USE K AND OF USE L DUE TO BY-PRODUCT Q

where: In_{IK} = the incompatibility cost of use K in location I to all other uses

f_{KLQ} = the functional relationship of cost of differential transmission of by-product Q between uses K and L

O_{KQ} = the operating standard of use K for the Qth by-product

G_{IJQ} = the relative incompatibility transmission rate from location I to location J for the Qth by-product

N = the number of locations

M = the number of uses

P = the number of by-products.

Little is known presently on the quantification of by-product incompatibility costs. Accordingly, it had been assumed that an average cost and transmission figure for all transmitted by-products between any pair of uses would be utilized. That is:

2.3 $$B_{KL} = \sum_{Q=1}^{P} f_{KLQ} (O_{KQ} - O_{LQ})$$

= the average utility lost due to the incompatibility effect of one acre of use L on one acre of use K when allocated to the same location or to adjacent locations I and J whose $G_{IJ} = 1$.

2.4 $$G_{IJ} = \sum_{Q=1}^{P} G_{IJQ} / P$$

= the average relative incompatibility transmission rate from location I to location J.

The incompatibility costs have been based on homogeneous uses in each location. For a location having a mixture of uses, these assumed costs will be in error for two reasons. The true incompatibility costs will be higher than those assumed in the model because smaller units have a greater interfacial contact per unit area and also a higher utility cost due to a lower average distance of separation of the

incompatible uses. But on the other hand, the designer will reduce the incompatibility by arrangement of the uses within the location, and this may tend to reduce the preceding errors.

Economies of Scale

In addition to by-product incompatibility, there is a relatively high return from the allocation of some uses in large blocks. It is in reality a reduction in activity costs, but it may be treated as a return in the objective function, since this maintains the proper relative values for allocation purposes. Note that these scale economies of a use are a cohesive force and thus are equivalent to a negative incompatibility of the use with itself. It was assumed that the economy of scale returns or savings are related linearly to the homogeneous use allocation size. Thus the incompatibility can be treated simultaneously with economies of scale. The economies of scale or negative incompatibilities then form the diagonal of the inter-use incompatibility matrix.

The Objective Function

The objective function or norm may now be stated as follows:

2.5 Maximize: $$\sum_{I=1}^{N} \sum_{K=1}^{M} R_{IK} \cdot X_{IK} - \sum_{I=1}^{N} \sum_{J=1}^{N} U_{IJ} \cdot F_{IJ}$$

$$- \sum_{I=1}^{N} \sum_{J=1}^{N} \sum_{K=1}^{M} \sum_{L=1}^{M} X_{IK} \cdot X_{JL} \cdot B_{KL} \cdot G_{IJ} - Fcc$$

subject to the constraints (refer to model equations 1.1 through 1.5):

1.1 $$\sum_{K \in S_T} \sum_{I=1}^{N} Y_{IK} \cdot X_{IK} = A_T \quad \text{for every T}$$

1.2 $$\sum_{K=1}^{M} X_{IK} = P_I \quad \text{for every I}$$

1.3 $X_{IK} \geq 0$ for every pair of I and K

1.4 $O_{IKL} = Z_{KL} \cdot X_{IK}$ for every combination of I, K and L

1.5 $$D_{JKL} = \sum_{I=1}^{N} O_{IKL} \cdot \frac{X_{JL}}{\sum_{H=1}^{N} X_{HL}}$$ for every combination of J, K and L

where: R_{IK} = the net location return from allocating one acre of use K to location I (note that this can equal either R_{IK}' or R_{IK}'' as discussed previously)

X_{IK} = the number of acres of use K allocated to location I

U_{IJ} = unit flow cost from location I to location J (excluding fixed channel costs)

F_{IJ} = the number of equivalent person trips from location I to location J

X_{JL} = the number of acres of use L allocated to location J

Fcc = the fixed (for a given transportation plan) component of channel costs

B_{KL} = the average utility lost due to the incompatibility effect of one acre of use L on one acre of use K when allocated to the same location or to adjacent locations I and J whose $G_{IJ} = 1$ (refer to equation 2.3).

G_{IJ} = the average relative incompatibility transmission rate from location I to location J (refer to equation 2.4).

N = the number of locations

M = the number of uses,

and; all trips must be distributed at least total cost in such a manner that trip origins and destinations in each location satisfy constraints 1.4 and 1.5.

THE MATHEMATICAL PROBLEM

There are many feasible configurations of activities within the plan area. The mathematical or design problem is to determine the best allocation of given activities within the constraints of the above model; that is, to determine the one feasible allocation of area uses, from a bounded set of many such feasible allocations, which maximizes return. Thus one of the mathematical programming techniques may be suitable. In the following section, the application of such techniques to similar problems is reviewed, followed by the presentation of a heuristic method which utilizes linear programming principles to obtain a good allocation plan.

The area use allocation problem is very similar to the plant and equipment allocation problems encountered in industry. The chief difference is that integer solutions may not be required for the allocation of all urban activities, as they often are in the industrial problems. That is, many of the urban units, such as a neighborhood, need not be of fixed area and/or capacity, but this may not be the case for industrial plant or equipment allocation. The application of the integer solution restriction to urban area use allocations can produce suboptimization.

In the land use planning field, an area use allocation model to minimize costs has been advanced by Schlager (1965). This model differs from the plant and equipment models, in that transportation costs for a given location initially are assumed to be independent of the allocation.

These costs are modified by feedback from the resultant allocation, and then a new allocation is obtained. A linear program is used to allocate area on the basis of a developmental cost which includes both adaptability and the above assumed transport costs.

Analogous Plant and Equipment Allocation Problems

The allocation of equipment and departments within an industrial complex is analogous to the urban area use allocation problems. The problem has been approached by graphic minimization and by mathematical minimization of transportation costs. In some cases, adaptability costs have been considered in addition to transportation costs.

Wimmert (1958) developed an allocation program which considered transportation costs between the centers of available locations. Since adaptability costs were not considered, an $n(n-1)/2$ by $n(n-1)/2$ matrix was used to represent flow costs between any two of n possible locations. The objective function minimized the sum of these costs by a procedure which essentially matched the largest volume flow path with the shortest distance, the second largest with the second shortest distance, et cetera. If constraints preclude assignment of some facilities to certain locations, the solution may have to be modified to obtain feasibility. Wimmert's solution procedure makes the following assumptions:

1. Only transportation costs are relevant.
2. Adaptability is either feasible or non-feasible.
3. Centers of potential locations are fixed and area requirements can be adapted to the available area in a feasible location.
4. Transportation costs are a linear function of volume-distance.
5. Flow occurs only between new facilities. Note, however, that this is circumvented simply by restricting an old facility to one location and treating it as a new facility.

Land (1963) presented a technique similar to Wimmert's using the n(n-1)/2 by n(n-1)/2 matrix of volume-distance cost, but obtaining a solution by a modified linear assignment procedure. The modification was the addition of constraints to preclude the assignment of one facility to more than one location. The procedure allocates pairs of facilities to pairs of locations. This generates a decision tree on which each branch is pursued until its costs exceed a known feasible solution. Like Wimmert's procedure, the assignment of uses a and b to locations c and d has only one cost, and thus Land's method also neglects differences of adaptability of use a to location c or d, or use b to location c or d. Land's other assumptions are the same as Wimmert's except that his costs are not constrained to a linear function of volume and distance. Economy of scale with respect to distance may be accounted for in the assignment procedure by suitable modification of the cost matrix. However, the method cannot account for the economies resulting from the aggregation of flows between several pairs of facilities on a common transport route mode.

Gavett and Plyter (1966) adapted the branch and bound technique to solve Wimmert's problem. However, as Willoughby (1967) notes, the computational efficiency of the resulting solution is not much greater than total enumeration.

Hillier (1963) presented a heuristic method of solving Wimmert's problem. An initial feasible allocation was examined for improvements by exchanging two adjacent departments. Since only two departments are interchanged simultaneously and only if they are adjacent, then the procedure will not in general yield an optimum solution since it does not identify other methods of improvement.

Buffa and Amour (1963) advanced a technique which is similar to Hillier's except that each use need not have the same area requirement, nor must each location centroid be known. As in Hillier's method, two adjacent uses are exchanged if a decrease in transport costs can be achieved. This procedure has been programmed and presumably could be extended to include adaptability costs.

Koopmans and Beckmann (1957) formulated the integer assignment of n plants to n locations with the objective of minimizing transport and maximizing location revenue, as a quadratic assignment problem. Lawler (1963) generalized the problem by including the location return as a negative transport cost from each location to itself; that is, the diagonal elements of the inter-location transport cost matrix. He presented a partition and bound solution in which the quadratic is partitioned into sub-problems. If the lower bound solution of the sub-problem is greater than a known feasible solution, then no expansion of the sub-problem is optimal. The optimal solution is obtained when no sub-problem remains with a lower bound less than the best known feasible solution. If the sub-problem had a lower bound than the known feasible solution, it is expanded until its lower bound exceeds this solution, or if it is completed, then it becomes the best known feasible solution.

Gilmore (1962) offered one optimal and two sub-optimal solution algorithms to the Koopmans and Beckmann problem. Since the optimal algorithm is inefficient or infeasible for more than fifteen locations, the sub-optimal algorithms would be utilized for larger problems.

Willoughby (1967) formulated the problem of allocating m uses to n locations, where m is less than or equal to n, utilizing any combination of given transport systems. The objective was to find an integer solution

which minimized costs within the constraint of a limited developmental budget. The solution procedure employed dynamic programming to select transport systems and allocate equipment simultaneously. With proper selection of stage sequence, the method will yield a good solution.

In each of these equipment and plant (area) allocation problems, it was assumed that an integer solution was required. In order to fit this format, urban area activities would have to be partitioned into units such as neighborhoods, industrial parks, shopping centers, et cetera. The size restrictions would produce suboptimization. If the assumption of interchangeable areas for each of these units were necessary as required by many of the above solutions, then the procedure would be of even lesser value. Furthermore, relaxing the integer allocation requirement might facilitate computations and at the same time produce an increase of the feasible solution set.

Schlager (1965) proposed a land use plan design whose objective function minimizes developmental costs. Constraints on the problem included plan objectives as design standards and future land and utility supplies. The plan design model received feedback from a land use simulation model which in turn received feedback from the transportation plan design. In addition, however, the input land use demands were modified by feedback from the land use-transportation plan. Essentially then, the model represents an iterative program for directing land use development to minimize development cost. The assumption of design standards may introduce suboptimality, while the feedback process is not likely to obtain the optimal solution because of the treatment of transport costs. These costs, insofar as they are considered, are assumed to be constant for a given location.

A Proposed Ascent Solution Procedure

Additional Assumptions

In addition to those made in the formulation of the model and the norm, the following assumptions were made to devise a practical solution procedure:

1. Given an existing solution, that a satisfactory area use move evaluator may be formed from an approximation of the change in the objective function which would result from a unit increase in that allocation in the given location (thus there will be one evaluator for each use in each location).

2. That the above evaluators may be calculated in three separate parts, corresponding to the first three terms of the objective function.

3. That the fourth term of the objective function, fixed channel costs, may be neglected in the formation of the evaluator. This will result in an attempt to optimize the use allocations for the given transportation plan.

4. That the change in the interactions of the area uses which have been moved simultaneously (without updating the evaluators) may be neglected in the formation of the evaluators, provided that the magnitudes of the allocation moves are limited.

5. That the flow cost contribution to a move evaluator (excluding fixed channel costs), although dependent on the magnitude of the move, can be approximated by one of two unit costs, again assuming that the magnitude of the allocation move is limited.

6. That a better solution will be obtained by decreasing each use allocation, and reallocating these uses with the objective of maximizing the sum of the products of the reallocated uses and their respective move evaluators.

The General Procedure

The solution procedure which has been developed to solve the problem requires an initial feasible solution (refer to step 1 of the algorithm given in a succeeding section). Then movements of the allocated uses, which would result in an increase in the objective function, are identified and some of the more beneficial moves are made. This forms a new initial feasible solution for repeating the entire process for the second

of several iterations.

The iterative procedure is utilized since the interaction effects of simultaneous moves are neglected in forming the evaluators of potential moves. As a result the evaluators must be updated periodically.

The primary decision variables in the procedure are the use allocations. But, the channels or transportation system may be modified on a judgement basis either between iterations or in some cases during iterations.

It is assumed that the sum of the changes in the objective function terms, when some use K is superimposed on the existing feasible plan in location I, is a satisfactory evaluator of the value of additional allocations of use K to location I. In the algorithm the above changes in the first three terms of the objective function are evaluated separately for every use in every location. Since the fourth term is not changed in land use evaluation, it may be neglected.

The unit change in the first term of the objective function is known exactly, since it is equal to the appropriate net location return. However, the second term, flow costs, is not related linearly to the change in allocation. Thus two unit flow cost estimators, which reflect an average change in flow costs for different amounts of change in the given use allocation, were developed and used in such a manner that the flow costs are never underestimated. This should result in a conservative evaluator of a potential move. With each successive iteration the amount of the overestimation is reduced, permitting the identification of the less desirable moves. These unit flow costs are calculated in steps 3 and 4 of the algorithm. Interaction effects due to simultaneous changes in several uses are neglected. The change in the third term of

the objective function, incompatibility costs, is calculated in step 2 of the algorithm for a unit increase in the given use. Thus it also neglects interaction due to simultaneous changes of several uses.

Once all of the evaluator components have been calculated, they may be combined. However, there are two net location return components (R_{IK}' and R_{IK}'' as discussed previously) and two flow cost components (to be discussed in detail in a succeeding section). The choice of the appropriate values is dependent on the level of the current allocations. For each use in each location there are four possible levels of the evaluator.

In order to permit reallocation of the uses, with the objective of increasing return, the problem is converted to a capacitated transportation problem. In step 5 of the algorithm the origins (unallocated activities) and destinations (uncommitted areas) are created by decreasing each use allocation in each location. The evaluators are then formed in step 6 for the new decreased allocation level. The evaluator then is equivalent to the flow cost of the transportation algorithm, but the problem is one of maximization rather than minimization. In step 7 a capacity limit on each additional allocation is imposed. This capacity is set equal to the lesser of:

1. The maximum amount that the use can be increased without resulting in an infeasible solution.

2. The maximum amount that the use can be increased without invalidating the evaluator; that is, up to the level at which either the net location return or the assumed unit flow cost changes.

Given the above capacitated transportation formulation, the initial levels of the dual variables are calculated and as much of the unallocated uses as possible are reallocated (see step 8). Because the

evaluators are not constant over the entire range of possible allocations, an optimal solution of the simplified problem may not be determined. In step 9, the evaluators, capacities, and dual variables are updated simultaneously and as many additional reallocations as possible are made. This step is repeated until all uses have been assigned.

Flow Cost Components for the Evaluators

Two unit flow costs, one for allocations at levels less than that of the previous allocation ($X_{IK(a)}$) and one for all other allocations, are developed (see Figure 9). In view of the basic premise that only one move at a time is considered in the formation of the unit costs, it may be shown that any increase in the allocation of use K to location I results in the attraction of trips at increasing cost. Thus, as the allocation of use K increases, the average flow cost for trips from use K in location I tends to increase and never decreases (see Figure 9). Note, however, that for low levels of the allocation the unit flow cost contribution to the objective function may be negative, since some trips are cancelled (discussed more fully below). It has been assumed that if the current allocation of use K to location I (X_{IK}) is less than that of the allocation in the previous plan ($X_{IK(a)}$), then the flow cost will be assumed equal to $C_{IK(a)}$. Therefore, if X_{IK} is less than $X_{IK(a)}$ the cost tends to be overestimated. In all other cases, the unit flow cost will be assumed to be equal to the average unit flow cost for an increased allocation of use K to location I, where this increase is the maximum permissible[1] ($X_{IK(c)} - X_{IK(a)} = \Delta X_{IK}$). This assumed unit flow cost

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[1]The maximum permissible increase is the lesser of:
1. The interchange limit (to be outlined in the next section).
2. The location size (P_I) less $X_{IK(a)}$.

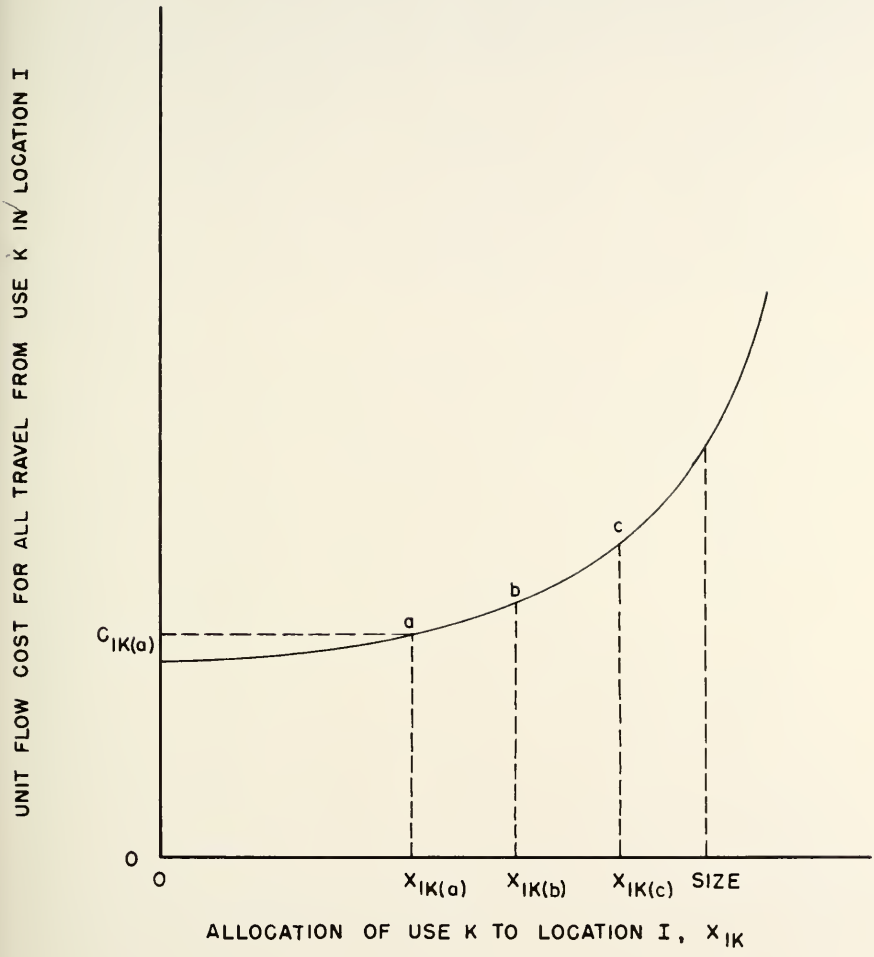

FIGURE 9. FLOW COSTS FOR USE K IN LOCATION I FOR A GIVEN ALLOCATION PLAN.

(C_{IK}') is equal to the area under the curve ABC divided by ΔX_{IK}. If, however, the new allocation level is less than $X_{IK(c)}$, such as $X_{IK(b)}$, then C_{IK}' is an overestimate of the theoretical cost, which would be the area under the curve AB divided by the net change in allocation over the previous solution. Thus it may be seen that no flow costs are underestimated and some are overestimated.

As the interchange limit is decreased on successive iterations, the maximum permissible allocation change will decrease, and thus the conservative bias of C_{IK}' tends to decrease also. This permits the identification of new moves, even if in lesser quantities and with lower net benefit.

In some cases $C_{IK(a)}$ may be greater than C_{IK}'. $C_{IK(a)}$ is calculated from the existing shadow prices[2]. But the shadow prices consider only flow costs and do not account for the savings resulting from the elimination of some inter-location trips. When X_{IK} is augmented, each X_{JL} is assumed to be augmented in proportion to its current level, so that all trips may be allocated. However, this means that some trips from location J to location I may now satisfy their destination use desire in location J resulting in a saving, and similarly some of the new trips originating in location I can now satisfy their destination in location I. These savings are not accounted for by the shadow prices because they consider only additional trips from pure origins to pure destinations, while in the above, some of the locations became both origins and destinations. On the other hand, these savings are accounted for in C_{IK}'

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[2]The shadow price of an origin is the change in the total optimal cost of all flows caused by a unit increase in the production at an origin. Similarly, the shadow price of a destination is the change caused by a unit increase in the trip attractions of a destination.

since it considers the total change in the objective function, which sums the cost of new flows less the savings due to flows which are eliminated. If $C_{IK(a)}$ is greater than C_{IK}', then $C_{IK(a)}$ is assumed to be equal to C_{IK}'. This will still result in an overestimation of the flow cost in many of these cases and thus the positive bias of the assumed unit flow costs is maintained.

Interchange Limits

It has been assumed that the average change in the objective function due to a temporary additional amount of a given use in a given location is an evaluator of the worth of increasing that use in that location. Provided that only that one move is made, and provided that its magnitude is equal to that of the temporary addition, then the evaluator is exact. However, if more than one move is made without recalculating the evaluator, the second and subsequent moves are based on incorrect evaluators. The error in the evaluator is due to neglect of the interaction term between the changed uses. Also, since the unit flow cost for a given use in a given location is dependent on the magnitude of that use allocation, the magnitude of the proposed move must be equal to that assumed in the formation of the unit flow cost, for the move evaluator to be exact.

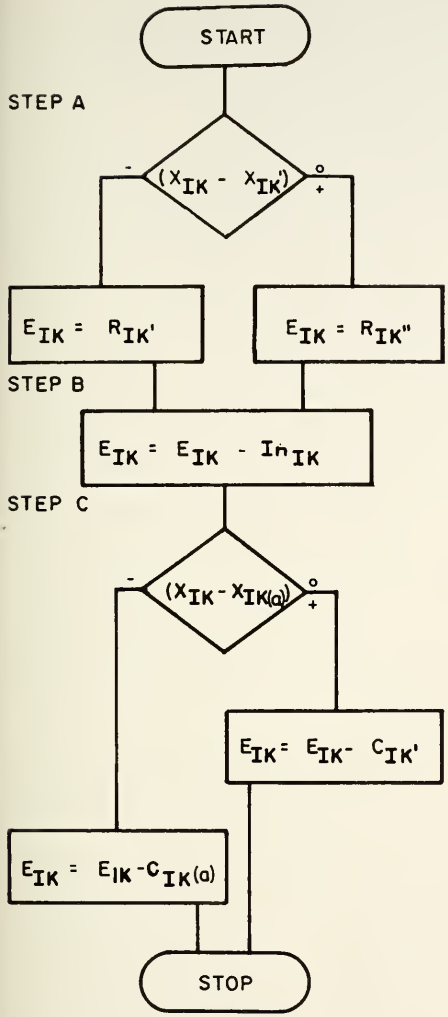
Both of these errors may be neglected, provided that only small moves are made before the evaluators are recalculated. Thus maximum interchange limits have been established. The magnitude of the limits will vary considerably, according to the type of use. For example, the interchange limit for the convenience shopping use would likely be much lower than that for low density residential use.

It may be noted that in step 10 of the solution algorithm (the conclusion of one iteration), the interchange limits are arbitrarily decreased by one-half of their current values. Since the larger of the assumed unit flow costs (one of the move evaluator components) is calculated for a maximum permissible increase in the allocation, the decrease in the limits results in a decrease in the assumed unit flow cost for the next iteration. The new flow cost leads to a less conservative move evaluator, and thus it permits the identification of less beneficial moves on the next iteration. Thus only the best moves are identified on the first iteration and successive iterations identify more and more potential moves but at continually decreasing net benefit per acre moved. The choice of the fraction (one-half) for the decrease in the interchange limit per iteration is completely arbitrary.

Minimum interchange limits have been provided as a device for terminating the algorithm. However, termination based on the rate of convergence towards an upper bound on the objective function certainly would be preferable if a reasonable estimating procedure for this bound could be devised.

Evaluator Synthesis

The formation of the unit move evaluators, the second phase in the solution procedure, is outlined in Figure 10. The appropriate location return is selected in Step A. In Step B, the unit incompatibility cost is subtracted from this return. Finally, in Step C, the algorithm selects one of the two unit flow costs (depending on the relationship of X_{IK} to $X_{IK(a)}$ as outlined above) and subtracts this cost from the output of Step B. The result (E_{IK}) is an evaluator of the return, net of cost,



I denotes the I'th location

K denotes the K'th use

X_{IK} = allocatin of use K to location I

$X_{IK'}$ = physically existing use K in location I

E_{IK} = unit move evaluator for use K in location I

$R_{IK'}$ = unit location return for reallocation of use K to location I

$R_{IK''}$ = unit location return for conversion of land in location I to use K from some other use

In_{IK} = unit incompatibility cost due to use K in location I

$X_{IK(a)}$ = allocation of use K to location I at the end of the previous iteration

$C_{IK(a)}$ = assumed average flow cost for x_{IK} less than $x_{IK(a)}$

$C_{IK'}$ = assumed average flow cost for x_{IK} equal to or more than $x_{IK(a)}$

FIGURE 10. FLOW CHART OF MOVE EVALUATOR FORMATION

for allocating one acre of use K to location I. Since the assumed flow costs have a positive bias, the evaluator tends to be conservative.

Termination of the Algorithm

No study of the speed of convergence of the algorithm towards the optimum was made. Nor was a satisfactory measure of the relative worth of a given solution devised. Also, a number of values such as the interchange limits, the reduction factor applied to the interchange limits at the conclusion of each iteration, and the amounts that each use allocation could be decreased for reallocation purposes, were chosen subjectively and were not evaluated in practice. Thus there are a number of factors related to the termination of the algorithm which are left for future study. The most important of these needs, however, is to find a better device for terminating the algorithm, such as the convergence towards a bound as mentioned previously.

The Solution Algorithm

The general solution algorithm proceeds as follows:

1. Find a feasible allocation of the required uses to the available locations (a good starting solution, such as an existing plan, will speed convergence towards the optimum).
2. Calculate the unit incompatibility cost (In_{IK}[3]), resulting from both negative and positive incompatibility, for an infinitesimal increase in X_{IK}. Repeat for every I and K. Set K = 0.
3. Calculate the inter-district flow costs and the inter-district components of the assumed unit flow costs as follows:

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[3]All terms are defined at the conclusion of the algorithm.

3.1 Set K = K + 1. If K is greater than the number of uses, go to step 4. Otherwise, set the flow evaluators, C_{DK}' and $C_{DK(a)}$, equal to zero for every D. Set L = 1.

3.2 Using the appropriate input inter-use and intra-use flows per activity unit and the current allocations, calculate origins and destinations for flow type KL (a flow type is designated by the origin and destination uses, respectively). Allocate these flows at least cost by means of a transportation algorithm, recording the district shadow prices, the individual total cost for each flow type, and the total cost for all flows allocated.

3.3 If a decrease in the allocation of use K to district D (X_{DK}) is feasible, utilize the shadow prices to calculate the cost savings for the reduction in inter-district flow type KL which would result from an infinitesimal decrease in X_{DK}. That is, the products of the shadow prices for the destinations and their respective fractions of the destination totals summed over all possible destinations, plus the shadow price of the origin. Add twice this saving to $C_{DK(a)}$. Repeat for every D.

3.4 Temporarily increase X_{DK} by Rm_K, the maximum interchange limit for use K. Assume that the destination use L is augmented at each district E in proportion to the current X_{EL}, such that the total number of new destinations is equal to the number of new origins created by augmenting X_{DK}. Calculate the new flows of

type KL and allocate them at least cost. Record the change in total cost for flow type KL divided by Rm_K. Add twice this figure to C_{DK}'. Decrease X_{DK} by Rm_K in order to revert to $X_{DK(a)}$. Repeat for every district, D.

3.5 Set L = L + 1. If L is less than or equal to the number of uses, return to step 3.2. Otherwise, return to step 3.1.

4. Calculate the inter-location flow costs and the inter-location components of the assumed unit flow costs (within the origin district only) as follows:

4.1 Set D = 0.

4.2 Set D = D + 1. If D is greater than the number of districts go to step 5. Set K = 0.

4.3 Set K = K + 1. If K is greater than the number of uses, go to step 4.2. Otherwise, set $C_{IK}' = C_{DK}'$ and $C_{IK(a)} = C_{DK(a)}$, where D denotes the district containing location I. Repeat for every $I \in S_D$. Set L = 1.

4.4 Using the appropriate input inter-use and intra-use flows per activity unit and the current allocations, calculate origins and destinations for flow type KL. Allocate these flows at least cost by means of a transportation algorithm, recording the location shadow prices and the total cost for flow type KL, and the total cost for all flows allocated.

4.5 If a decrease in X_{IK} is feasible, calculate the intra-location cost savings for the reduction in flow type KL

which would result from an infinitesimal decrease in X_{IK}. That is, the products of the shadow prices for the destinations and their respective fractions of the destination totals, summed over all locations within the district. Add twice this saving to $C_{IK(a)}$. Repeat for every $I \in S_D$.

4.6 Temporarily increase X_{IK} by the maximum permissible amount, ΔX_{IK}. Assume that the destination use L is augmented at each location J in proportion to the current X_{JL}, such that the total number of new destinations over all destinations in all districts is equal to the number of new origins created by augmenting X_{IK}. Calculate the new intra-district flows of type KL and allocate them at least cost. Record the change in total cost for flow type KL divided by ΔX_{IK}. Add twice this figure to C_{IK}'. Decrease X_{IK} by ΔX_{IK} in order to revert to $X_{IK(a)}$. Repeat for every $I \in S_D$.

4.7 Set L = L + 1. If L is less than or equal to the number of uses, return to step 4.4. Otherwise return to step 4.3.

5. Reduce every X_{IK} ($X_{IK} = X_{IK(a)}$ prior to this reduction) by either $0.5 \cdot Rm_K$ or $X_{IK(a)}$, whichever is the lesser. Record the amounts of each use left unallocated and of each location left uncommitted.

6. Calculate the move evaluator E_{IK} for every I and every K (see Figure 10).

7. For every I and K, calculate Cap_{IK}, the maximum amount that X_{IK} may be increased without invalidating E_{IK} as calculated in step 6. Cap_{IK} is the least of:

   a. The location size ($size_I$) minus X_{IK}.

   b. X_{IK}' minus X_{IK}, for X_{IK} less than X_{IK}' only (X_{IK}' denoted the physically existing level of use K in location I).

   c. $X_{IK(a)}$ minus X_{IK}, for X_{IK} less than $X_{IK(a)}$ only.

   d. $X_{IK(a)}$ plus Rm_K minus X_{IK}.

8. Allocate as much of the unallocated uses as possible by means of a capacitated transportation algorithm at the initial shadow price (dual variable) levels.

9. Re-evaluate all E_{IK} and Cap_{IK} and then revise the shadow prices. Allocate as much of the unallocated uses as possible. Repeat this step until all uses have been allocated.

10. Reduce Rm_K by one-half of its current value for every K. If the new values are more than the minima set as criteria, and if further improvements seem possible, return to step 2.

where:

In_{IK} = the incompatibility cost produced by allocating one acre of use K to location I

$$= \sum_{J=1}^{N} \sum_{L=1}^{M} (B_{KL} + B_{LK}) \cdot X_{JL} \cdot C_{IJ}$$

B_{KL} = average utility lost due to the incompatibility effect of one acre of use L on one acre of use K when they are allocated to the same or adjacent locations

X_{JL} = allocation of use L to location J

C_{IJ} = average relative incompatibility transmission rate from location I to location J

N = number of locations

M = number of uses

ϵ denotes "an element of the set of"

C_{DK}' = average cost of inter-district flows resulting from the increase in allocation of use K from $X_{DK(a)}$ to $X_{DK(a)} + Rm_K$

$$= 2 \cdot \left(\sum_{L=1}^{M} \sum_{E=1}^{P} F_{DEKL}' \cdot C_{DE} - \sum_{L=1}^{M} \sum_{E=1}^{P} F_{DEKL} \cdot C_{DE} \right) / Rm_K$$

P = number of districts

X_{DK} = allocation of use K to district D

F_{DEKL} = net flow of type KL from district D to district E for $X_{DK} = X_{DK(a)}$

$$= T_{KL} \cdot \frac{(X_{DK} \cdot X_{EL})}{\sum_{F=1}^{P} X_{FL}} - F_{EDKL}, \text{ for } F_{EDKL} < \text{the first term,}$$

$$= 0 \text{ in all other cases}$$

F_{DEKL}' = net flow of type KL from district D to district E, for $X_{DK} = X_{DK(a)} + Rm_K$

T_{KL} = number of trips from one acre of use K destined to some use L

C_{DE} = minimum cost of flow for one trip from district D to district E

Rm_K = maximum interchange limit for use K

$C_{DK(a)}$ = average saving in inter-district flow costs due to an infinitesimal decrease in X_{DK}

$$= 2 \cdot \left(\sum_{L=1}^{M} Pr_D \cdot T_{KL} - \sum_{L=1}^{M} \sum_{E=1}^{P} Pr_E \cdot T_{KL} \cdot \frac{X_{EL}}{\sum_{F=1}^{P} X_{FL}} \right)$$

Pr_D = shadow price of district D

X_{EL} = allocation of use L to district E

C_{IK}' = average cost of flows resulting from an increase in X_{IK}, where location I is in district D

$$= 2 \cdot \left(\sum_{L=1}^{M} \sum_{J \in S_D} F_{IJKL}' \cdot C_{IJ} - \sum_{L=1}^{M} \sum_{J \in S_D} F_{IJKL} \cdot C_{IJ} \right) / \Delta X_{IK} + C_{DK}'$$

F_{IJKL} = net flow of type KL from location I to location J for $J \in S_D$ and $X_{IK} = X_{IK(a)}$

F_{IJKL}' = net flow of type KL from location I to location J for $J \in S_D$ and $X_{IK} = X_{IK(a)} + \Delta X_{IK}$

S_D = set of locations comprising district D

C_{IJ} = minimum cost of flow for one trip from location I to location J

ΔX_{IK} = maximum permissible increase of allocation of use K to location I

$C_{IK(a)}$ = average saving in flow costs due to an infinitesimal decrease in X_{IK} where location I is in district D

$$= C_{DK(a)} + 2 \cdot \left(\sum_{L=1}^{M} \sum_{J \in S_D} Pr_J \cdot T_{KL} \cdot \frac{X_{JL}}{\sum_{H=1}^{N} X_{HL}} \right)$$

Pr_J = shadow price of location J

R_{IK}' = location return for conversion of land in location I to use K from some other use

R_{IK}'' = location return for reallocation of land in location I to the existing use K

Computer Programs

Two series of computer programs were developed to carry out the calculations. In the first series of programs, INCOMP carried out step 2, FLOCOST step 4 (step 3 was omitted since there was effectively only one district), and REALOC steps 5 through 10, inclusive. This series was developed and tested with the hypothetical data shown in Appendix B. Later these same programs were revised to handle the Lafayette, Indiana Plan Area data, by making extensive use of disk storage. This proved to require excessive peripheral and central processor time.

Consequently, the second series of programs was devised to compute the flow costs in two parts, one component for inter-district flows and one for intra-district flows. INCOMP was unchanged from series 1, but DUAL1 and DUAL2 were developed to handle the inter-district and intra-district flows, respectively. The combination of inter-district and intra-district evaluator components, called for in step 4, was omitted from DUAL2 in order to permit more flexibility in the program development. REALOC LAFAYETTE USES then completed the remainder of the algorithm. This last program is simpler than its series 1 counterpart, REALOC, since it did not have to be designed to handle multi-use activities.

All of the programs, except INCOMP, make extensive use of variants of the out-of-kilter network algorithm (Fulkerson, 1961). This algorithm was chosen for the ease of programming and because it rapidly solves network and transportation problems which are minor modifications to problems previously solved. Steps 3.4 and 4.6 of the algorithm require many such modifications of the results from 3.2 and 4.4, respectively.

Discussion of the Data for the Lafayette, Indiana Plan Area

Data collection and compilation techniques are major problems in the application of any new type of model, and since a large scale application provides a good test of the model it was deemed advisable to apply the model to a city. The community chosen was the Lafayette, Indiana urban area.

Since the model was still in the developmental stage, requiring periodic changes, many simplifications in the assembled data were permitted to facilitate modifications, and to provide a rapid means of testing the procedure. However, data simplifications which might have invalidated the test were not permitted.

In place of utility, the common metric used to evaluate alternatives was the dollar. This simplification then implies the assumption that all individuals place the same value on the dollar. This is clearly not true, but it is not an unreasonable approximation to the average utility and it is justifiable in view of the lack of current knowledge on the dollar-utility transform.

The required area uses were based not on activities but primarily on land use forecasts as determined by the Lafayette Area Plan Commission. These requirements are shown in Table C1. Since the requirements specified uses rather than activities, thus precluding density changes for any given activity, a degree of suboptimization was introduced. This suboptimization would be greatest in the residential categories. The residential activities normally would be shifted by the solution procedures towards the higher density uses, such as apartments, as

the urban area grows, yet the requirements as stated indicate the reverse. Since public lands other than parks form a very small percentage of area uses and are either fixed or are an integral part of residential uses, for example elementary schools, these areas were either deleted from consideration or aggregated with residential. Cemeteries were deleted from consideration entirely since they use a small percentage of land, they are virtually fixed, and intercourse between cemeteries and other areas is neither significant nor predictable.

The available locations were assumed to be all usable land within an area approximately 8.5 by 8.5 miles, which encompassed all the urbanized areas contiguous to Lafayette and West Lafayette. The locations are shown in Figure C1. However, all cemetery, river, lake, and flood plain areas were deleted from consideration as usable land. As mentioned previously, some other public lands were also deleted from consideration on an individual judgment basis. It was assumed initially that all lands which were designated for development by Purdue University be considered fixed, that is, these locations could not be employed for any other use. This condition was insured by the assignment of an arbitrarily high return for their use by Purdue University. In all locations gross areas were used, since street requirements vary with the particular use and may be considered an integral part of the use. In order to satisfy the model requirement of approximately equal location areas and also to minimize mixtures of uses within locations without producing a computationally infeasible problem, the average location size was set at 0.5 by 0.5 miles. This size also permitted the use of many arterials as location boundaries. Location boundaries

were set on the basis of judgment; to maintain equal areas,[4] to maintain similarity of topography and land use, to coincide with natural and cultural communication barriers or channels, and to separate areas of similar traffic entry and exit points.

Location returns were based solely on the return due to absolute location (adaptability), since activities had been preassigned to given uses. These data were based on estimates of changes in real estate values due to differences in existing cultural facilities, topography, foundation, drainage, and other resource values of the particular site. The major figure in these calculations for developed areas was the value of cultural facilities.

In order to convert all cost and return data to the same basis, it was assumed that the change in real estate values could be converted to an annual cost on the basis of 6 percent interest plus capital recovery over a twenty-five year period. For a more precise evaluation, this procedure might be varied to suit the particular component of adaptability. For instance, topography rating should include only interest since usually there would be little depreciation in the topography rating. In order to evaluate existing cultural facility values, the amount of each type of land use in each location was measured from aerial photographs taken in 1963. A worksheet used to record these data is shown in Figure C3. This survey included the average density of a sample residential block in each fully built-up location, and

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[4] In some cases this restriction was relaxed if no incompatibility cost errors were thereby introduced.

the average rooftop area of four houses within that block. The block and the houses were chosen at random. The aerial photograph survey was supplemented by ground reconnaissance to determine, by judgment, the following average values for each existing residential location:

1. Number of stories of residences
2. Condition of residences
3. Single or multi-family occupancy

These two surveys plus the data shown in Tables C2 and C3 were used in the evaluation of cultural facility values except for residential facilities in partially developed locations. For these locations, residential facilities were evaluated by judgment and observation of stereo pairs of the aerial photographs. If there were five or fewer homes in an otherwise vacant location, their net value was generally assumed to be zero. The aerial photograph survey, with the aid of topographic maps, also included a topography rating of each location by absolute slopes plus a subjective modification based on the frequency of change of slope. In general, a low slope rating indicated an average slope of less than 3 percent, a medium rating slopes of 3 to 6 percent, and a high rating a slope of more than 6 percent. Foundation and drainage ratings were derived from maps in the Tippecanoe County Soil Survey (United States Department of Agriculture, 1959). Broad parent soil groupings are shown in Figure C1. By using the data from Table C4 plus the above ratings, differences in location real estate values, and thus relative annual adaptability costs, were determined. Since the limited data available indicated similar adaptability costs for most uses, only differential drainage costs in bottom lands, other than flood plains, were assigned. It might be

noted that two sets of return data have been developed, one set for a change of use from the existing use (including vacant) to another use, and one for a reassignment of the existing use. This is requisite in all partially developed areas. In order to determine which return is currently applicable, the existing land uses, as previously determined, were also input to the computer program.

Intra-use flows were not considered in the model. This deletion does not introduce serious errors since the destinations of such trips tend to be distributed uniformly. However, it was in fact omitted, because the transportation algorithm employed automatically deletes such trips. This topic will be covered more fully in the general discussion. The inter-use flows shown in Table C5 were based on data obtained by Golenberg (1966) for the Lafayette area plus judgment and typical inter-use flow rates in Chicago (CATS 1959). However, trips between two different residential uses were assumed to be zero to agree with the zero intra-use trips discussed above. Again, this will be discussed more fully in the following section. All Purdue University trips were assigned to the main campus location.

In order to derive flow costs, the proposed arterial, parkway, and interstate network within the plan area, as shown in Figure C2, was compiled from maps issued by the Lafayette Area Plan Commission and the County Engineers' Office. The travel distance on each link of this network was measured. Distances on local streets were assumed equal to the sum of the latitude and departure of the link. By using a time value of 1.5 dollars per hour, the average speeds shown in Table C6, and a distance cost of 0.1 dollars per mile, these link distances were converted to unit link flow costs. These subsequently

were converted to unit annual flow costs and input to a computer program, which had been developed by W. C. Vodrazka (1968), in order to determine the minimum flow costs between all pairs of locations.

Inter-use incompatibility costs were derived by estimating the change in real estate values due to the allocation of two uses to adjacent locations. Negative incompatibility was not considered. The decrease in value was converted to an annual cost by the same procedure as was used for adaptability costs. The data are shown in Table C7.

By-product transmission values were based on the estimated data shown in Table C8. Arterials and parkway barriers were assumed to exist at all borders coinciding with existing or proposed arterials and parkways. Natural barriers were determined from the aerial photograph survey, and interfacial contact was measured from the location map (Figure C1).

Interchange limits were set by judgement, and are shown in Table C9.

Subsequent to the preparation of the Lafayette data, it was found to be necessary to group locations into districts. The results are shown in Table C10. It would have been preferable to define the districts, paying particular attention to their access to major throughfares, prior to the location definition. However, the resultant districts provided the necessary test of the modified procedures.

DISCUSSION AND RESULTS

The research which culminated in the formulation of the above model was initiated to provide a normative means of area use allocation resulting in maximum net community return. As such, each location factor which affected community goals had to be included in the model. From the research it was decided that the factors to be incorporated in the objective function were transportation, incompatibility, and adaptability costs. It was recognized, however, that a great deal of research will be required to quantify these costs accurately and precisely, and that some assumptions regarding the inputs were required.

The primary assumption was that all costs can be represented satisfactorily by piecewise linear approximations. This requires that the data supplied to the model be chosen for the expected range of the solution variables. Since land use allocation is not sensitive to small changes in the input data, this should not be a serious limitation.

A second major assumption in the solution procedure was that the transportation costs are fixed. This is a serious drawback, since it requires that each transportation plan be studied separately. Even so, if the initial iterations in the solution procedure indicate that improvements, such as upgrading arterials to freeway status, may reduce overall costs, the new plan may be evaluated by changing a few data plus a minimal amount of computation. Since the inter-district and

intra-district flow costs are computed separately, changes in the major thoroughfare plans and addition of congestion tolls to reduce unrealistically high volumes, might be made without repeating the entire iteration. Some cost of flow values and the size and characteristics of a few locations along the new facility might be altered. The iteration could proceed with the new data, or if necessary, be completed with the existing data and modifications made at that stage. Since the final program calculates a total net return for each iteration, two or more alternative transportation plans may be compared by means of their respective return figures.

The third major assumption required for the solution was that the rate of generation of trips, and thus the major cost, was independent of the solution. This may not be true, but by proper calibration of the trip rates, the resultant errors will be minimized.

Finally, the solution procedure considers only a deterministic static case. If the static case is a distant horizon year, the resultant solution may not be satisfactory for the aggregate of the intervening years. A potential modification of the model to provide a good solution over a long term would be to construct the evaluators as the sum of several components. Each component should reflect the average value of a given allocation over a given period. The evaluator components for distant time periods might be inaccurate, but the relative worth of different plans should still be reflected by them. In any case, we are concerned primarily with the near future since the present worth of distant years is very small. Thus it appears that the static case assumption may not prove to be a major drawback to applications of

the model.

The consideration of the deterministic case has led to the deletion of all intra-use flows. In the transportation algorithm utilized, all intra-use flow destinations and origins are allocated to the same location since this results in least cost. The true selection of a trip destination is not always to the least cost location even though the probability of such a selection is high. Thus errors are introduced. Similarly, not all inter-use trips will follow the least cost route. But, provided that the use categorization is sufficiently definitive to make the probability of trip allocation to the least cost route approach 1.0, then the solution will provide the opportunity for rational choice of low cost trips. Certain types of trips, such as the inter-residential social-recreation trips, may be best deleted from the model since the destinations of these trips deviate considerably from the economist's rational choice and are not easily predicted. Thus it should be noted that the intra-residential flows were deleted from the Lafayette input data. Some inter-use flows may be deleted advantageously if their volumes are low enough that their effects on the solution are insignificant. These deletions could reduce the computations considerably.

Although external-internal trips were not considered in the Lafayette model, this may not be advisable in practice, since such trips will affect some use allocations. Dummy external zones whose trip loading points are placed at the intersection of major arterials or highways near the plan area boundaries, may be used to consider their effect.

One of the drawbacks to the solution algorithm proposed herein, is that successive applications of the transportation algorithm to various

trip types precludes capacitation of transport routes. It has been assumed that such route capacities can be increased as required. However, it is hoped that the multi-commodity transportation algorithms will be improved to the point where they may be substituted for the present algorithm, but with desired capacity constraints. Using the present algorithm, volumes could be limited only by calibrating the flow costs to reflect congestion.

When the flow cost calculations were split into two components, it was decided to permit potential underestimation of the inter-district flow cost component. It was felt that if this component was always calculated with a maximum permissible increase of the given use in the given district, that the conservative bias of the corresponding move evaluator might be excessive. The advisability of this modification should be checked in a detailed study of convergence. In any case, reversion to the maximum permissible increase for the district, rather than the maximum interchange limit, is a minor change technically. Another problem raised by the split, was potential invalidation of the origin shadow price since it will, in general, differ when determined by DUAL1 and when by DUAL2. However, it should still be a practical and reasonable approximation. The increase in the speed of computations, and the ease of varying the major thoroughfare system pricing, more than offset the resultant deficiencies.

Because of the macroscopic nature of the model, the data it requires need not be more detailed than conventional land use model data. However, there is very little known on area use economies of scale (negative incompatibility), positive incompatibility due to by-product transmission,

and the dollar-utility transform. All of these areas currently are considered on a subjective basis in planning. The provision of this model permits their quantitative consideration, and hopefully may help stimulate research in each of the areas. Also, the area of goals formulation and evaluation requires further research.

It may be noted that incompatibility costs were considered only between adjacent locations in the Lafayette application. This can be extended to any number of locations for such by-products as smoke, which may cover a considerable area on the lee side of prevailing winds. The additional computation time is trivial, and additional computer storage requirements would likely not be a problem.

Although the model was developed for use on one urbanized area, the same methodology could be applied, for example, to the design of a region or neighborhood. Major modifications would be required in the input data. For instance, in neighborhood design the walking trip would be a significant factor.

Computer expenditures required to carry out one iteration of the algorithm are small relative to ordinary planning costs. Also, the input data are limited. Consequently, it would appear that it would be economical to use the model, even if many iterations of the procedure were required to evolve a satisfactory transportation system. There does not appear to be any objection to the application of the model to very large areas since the second series of programs did not present core storage problems nor require excessive computation time.

In the Lafayette application, economies of scale were neglected. This was partly due to a lack of knowledge of the appropriate data, but

a more important reason was that the use categorization used for the test did not appear to be sufficiently definitive to realistically apply average scale economy factors. Although this certainly casts some doubt on the true value of the results, the test served its purpose, which was merely to test whether the procedures are practical.

To the author's knowledge no previous land use model has provided a generalized method to consider positive incompatibility of proximate uses and the economy of scale of contiguous use allocations on an objective basis. Furthermore, the periodic re-evaluation of communication costs, through the cyclical reconstruction of the move evaluator matrix, permits interchanges to be made such that the net return is increased rapidly. The provision of alternative uses to provide for given activities precludes suboptimization due to a priori assumptions of the type of accommodation needed for the given activity. Finally, the model simultaneously considers and allocates all types of land use. Although the procedure employed utilizes some approximations, it does identify all significant methods of improvements except in transportation system components, and will permit the interchange of any group of uses, irrespective of their locations, in any one iteration.

One of the most important of the model's potential applications is the simultaneous consideration of allocation and reallocation of future and existing uses. This permits the planning of urban renewal in conjunction with new developments. The model will identify the areas which may be converted to a different activity or upgraded to another use, in view of all other existing and proposed uses.

The results of one iteration of the procedure on the sample data for a hypothetical community are shown in Table B8. The change in allocation resulted in decreases in transportation and incompatibility costs of 20.4 and 26.7 percent of their original values, respectively. There was no significant change in location returns. Although the example was highly simplified, it demonstrated that the procedure can improve the net return and that the programs operate satisfactorily.

Sample results of the input allocation and the output reallocation for the Lafayette application, after one iteration, are shown in Tables C11 and C12, repectively. To cite specific results from these tables, note that the allocation of uses 2 (medium density residential) and 3 (low density residential) to location 53 were reduced by 5 and 20 acres, respectively, and this land left to the vacant use (10), which is not shown. In location 86, 20 acres of use 5 (industrial research) was converted to use 3.

CONCLUSIONS

It has been concluded from the above research:

1. The literature search and the synthesis of known principles, hypotheses and data have shown that all major factors influencing land use allocation can be incorporated in a model as; gross utility return due to adjacent allocation of uses which have economies of scale, utility cost due to proximate allocation of uses with differential by-product operating standards, utility cost due to transportation, and the utility cost of adapting a use to a given location.
2. The gross utility return from area allocated to a given use will not affect the allocation unless the community controls its growth and does not permit choice of the optimum use(s) for a given activity. Since the latter condition is rarely true, although usually assumed in planning, a knowledge of space preference is needed to prevent the resultant sub-optimization.
3. The utility return due to economies of scale cannot be adequately considered without more definitive use categorization than was utilized in the Lafayette application of the model.
4. The utility cost due to incompatibility should be considered on the basis of individual, rather than average, values for

each by-product. But this requires more detailed knowledge of the incompatibility processes and their effect on local community goals than is currently available.

5. That the solution procedure developed herein may be used to obtain a good plan for the given requirements, where good implies a plan which provides near maximum net utility return.
6. Since travel cost is a major factor in the solution procedure, and time is an important component of this cost, a variable inter-location flow cost, dependent on the trip type, should be investigated for any application of the model.
7. That the possibilities of varying both the transportation system components and the land use allocation, as discussed previously, should be researched.
8. That the computer programs presented herein satisfactorily carry out the solution procedure.
9. That by utilizing the model, the model solution procedure, and the computer programs provided, an efficient plan may be devised rapidly for a city at least as large as the combined areas of Lafayette and West Lafayette, Indiana.
10. That the initial step in the application of the model should be an investigation of the solution convergence, and in particular, the interchange limits.

RECOMMENDATIONS FOR FUTURE RESEARCH

Since the above model and its normative solution procedure have been developed from a basic study of allocation of area uses, and since the solution implies a relatively new concept, namely normative plan design, the research has pointed up many outstanding areas for potential research. These areas have been categorized as alternative model structuring, alternative or improved solution procedures, data needs and acquisition, and practical applications and extensions of the model to other areas.

Alternative Model Structuring

The above model has been structured around the premise that significant urban area use returns and costs can be represented satisfactorily by linear transport costs, site adaptability returns, scale economy returns, and incompatibility costs. The choice of linear returns and costs was made partly to facilitate the solution and partly because of a lack of knowledge of the true processes. For instances, in the case of transport, the costs are known to be a non-linear function of volume, but by proper calibration, linearity usually can be assumed without serious error. In the case of economies of scale, the returns may well be non-linear but until it is investigated the linear assumption is better than total neglect. Also, economies of scale may be partially considered as intra-use flows. Thus an investigation of this aspect might lead to the

addition of a fifth term to the objective function for intra-use flows, as well as modifications to the existing negative incompatibility term. As knowledge of the land use allocation process grows and new solution procedures are developed in mathematical programming, the model structure and content could be reviewed for potential modifications.

One specific area of needed improvement in the model is the imposition of an effective route capacity, preferably by means of a representative non-linear transport cost. Also, the assumed linearity of both negative and positive incompatibility should be verified or modified.

The most outstanding need in the model, however, is to incorporate the selection of alternative transportation system components in concert with the land use allocation.

It was noted in the discussion that the model had been structured for the static deterministic case. The relaxation of both of these restrictions should be explored. For instance, even if the deterministic solution procedure is retained, flow costs could be weighted on the basis of probability of selection of the least and lesser cost routes. However, the use of a total present value solution based on the sum of the move evaluator components for several time periods seems to offer the greatest potential for improvement.

Alternative and Improved Solution Procedures

One alternative to the proposed solution procedure which could be investigated, is the use of quadratic or neo-quadratic programming techniques in order to consider the multi-move interactions. This would produce a more complex procedure, but could reduce or perhaps even eliminate the need for iteration of the solution procedure.

If, however, the existing overall solution procedure is retained, the transportation algorithm offers the best area for improvement, since it requires the most time and the most core storage. The storage and/or computation time may be reduced by area partitioning and/or zone aggregation. Alternatively, the use of a multi-commodity transportation algorithm may become a practical substitute. This would permit simultaneous consideration of trip types and thus permit the route capacitation mentioned earlier.

Turning to termination of the algorithm, convergence of the subsequent solutions towards the optimum was not investigated. It may be that some of the arbitrary values, such as interchange limits, could be modified to improve the solution efficiency. But, the best method of improving the convergence would be to estimate an upper bound on the return for the best solution. This could be built up on a term by term basis. A bound for the first term could be calculated easily by allocating uses to locations to maximize net location return (disregarding all flow and incompatibility terms). A bound for the incompatibility term could be determined by allocating uses in blocks subjectively, attempting to minimize the difference in operating standards of adjacent uses and to take full advantage of transmission barriers such as rivers. The flow costs term presents the greatest difficulty. However, a bound could be estimated by allocating the uses by a procedure similar to Wimmert's, or even by utilizing Gilmore's solution procedure (refer to the preceding Analogous Plant and Equipment Problems). A fraction of the uses could be allocated in blocks but the fraction should be chosen such that the flow cost estimation is minimal but realistic. That is, each block should be representative of the least amount of the use which might be

allocated alone (as the block sizes decrease the flow costs decrease and thus the net return increases). An estimated bound for flow costs would then be the product of the average cost for the allocation of the above uses and the total amount of uses. Finally, a lower bound on the transportation system cost could be established subjectively. An upper bound on the total net return then would be the sum of the above bounds. This sum could be used as one measure of the speed of convergence and whether or not to continue the iterations.

Data Needs and Acquisition

There is a need in land use planning for a more detailed knowledge of the land use selection process. The areas of space preference in use choice for a given activity, economies of scale in land uses, incompatibility of land uses, and the effect of transmission barriers on incompatibility costs offer outstanding areas of research. A suggested initial study would be a statistical analysis of their effects on land values. This study should be oriented towards a knowledge of the required model variables, their relationships, and the required accuracy of measurement of the input model data.

Since transport costs are one of the most important classes of input data to the model, the assessment of travel time cost and its relationship to trip purpose should be investigated. A related area is the relationship of trip desire and cost. This latter area is of most importance in planning new areas where calibration based on present conditions is not possible.

Practical Applications and Extensions

Although it has been shown that the above model can be applied to a smaller city, research could be initiated into applications to large metropolitan urban areas. It is possible that in the largest areas this might require a system of linked models similar to those solved by the decomposition algorithm. Also, research should be directed towards applications to regions for the purpose of rationalization of trade centers and effective long-range planning of inter-center transportation and other community services.

Since the model utilizes an evaluation procedure which simultaneously considers both the land use and transportation aspects of a plan, the application of this procedure to the evaluation of alternative land use-transportation plans should be investigated.

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APPENDIX A

APPENDIX A

COMPUTER PROGRAMS FOR THE SOLUTION PROCEDURE

A1. INCOMP

The data required for INCOMP is; the existing use allocations (AL)[5], a list of proximate locations (ITR) for each location I and the transmission between these locations and location I (TRA), and the differential operating standards between any two uses (OP). The vacant use must be last in any data list.

The program calculates the additional incompatibility caused by a unit increase in allocation of each use to each location (SUMJ2), that is a two-way incompatibility, for the move evaluators. A second figure, SUMJ1, is a one-way incompatibility cost total used to determine the sum of all incompatibility for comparison of subsequent iterations.

In this program, and those following, the internal storage for unused locations, such as those on flood plain areas, was deleted. For example, in the Lafayette application there were 289 numbered locations, but these were treated as 258 locations for storage, calculation and program indexing purposes.

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[5]The bracketed names denote the matrix or variable name used in the programs.

```
3291,GRECCD,T30,CM70000,P10.
RUN(S)
LGO.
7
C
C                              INCOMP  TEST
C
C
C1  CALCULATES SUM OF NEGATIVE AND POSITIVE INCOMPATIBILITY
C     DUE TO AN INFINITESIMAL INCREASE IN THE GIVEN USE IN THE
C     GIVEN LOCATION (ALL OTHER USES ASSUMED FIXED)
C2  OUTPUT IS REALOC INPUT
C3  THE DIMENSIONS ACCOMODATE 10 USES AND 258 LOCATIONS.
C     ALTER VARIABLE USE AND LOCATION DELIMITERS TO SUIT
C     PARTICULAR APPLICATION
C4  THIS PROGRAM HAS NOT BEEN WRITTEN FOR A SPECIFIC SYSTEM
      PROGRAM INCOMP(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=
     1PUNCH)
      DIMENSION RINC(10,258),IS(8),ITR(8,258),TRA(8,258),AL(10,258),
     1DP(10,10),NO(289)
C  VARIABLE USE AND LOCATION DELIMITERS
      NUSE=6
      LI=9
      LJ=9
      NP=NUSE+1
C INPUT
      READ(5,1)((DP(K,L),K=1,10),L=1,10)
    1 FORMAT(10F8.2)
      WRITE(6,1)((DP(K,L),L=1,10),K=1,10)
      DO 500 I=1,LI
  500 READ(5,2)(AL(K,I),K=1,10)
    2 FORMAT(10X,10(3X,F3.0))
      WRITE(6,1)((AL(K,I),I=1,10),K=1,10)
      DO 501 J=1,LJ
    4 FORMAT(6X,8(I4,F3.1))
  501 READ(5,4)(ITR(I,J),TRA(I,J),I=1,8)
      TOT=0.
      DO 100 K=1,NUSE
      DO 100 I=1,LI
      SUMJ1=0.
      SUMJ2=0.
      DO 101 L=1,NUSE
      SUMJ = 0.
      DO 102 JT=1,8
      JX=ITR(JT,I)
      IS(JT)=JX
      IF(JX.EQ.9000) GO TO 300
    8 FORMAT(2I4,F10.1)
  102 SUMJ=SUMJ+AL(L,JX)*TRA(JT,I)
      SUMJ1=SUMJ1+DP(K,L)*(SUMJ+AL(L,I))
  300 IF(K-L) 200,201,200
  200 SUMJ2=SUMJ2+(DP(K,L)+DP(L,K))*(SUMJ+AL(L,I))
      GO TO 101
  201 SUMJ2=SUMJ2+DP(K,L)*(SUMJ+AL(L,I))
    3 FORMAT(1X,11I7,2F15.1)
  101 CONTINUE
      TOT=TOT+SUMJ1*AL(K,I)
      RINC(K,I)=SUMJ2
  100 CONTINUE
      WRITE(6,5)TOT
    5 FORMAT(E20.7)
```

```
      WRITE(6,6)((RINC(K,I),I=1,LI),K=1,NUSE)
      PUNCH 10,((RINC(K,I),I=1,LI),K=1,NUSE)
    6 FORMAT(1X,1P10E13.5)
   10 FORMAT(1X,1P7E11.4)
      STOP
      END
C                              SAMPLE DATA
C  OPERATING STANDARD DIFFERENTIAL (OP) IN DECREASE IN DOLLAR
C VALUE PER ACRE. THE FIRST CARD GIVES OP FOR USE 1 TO USES
C  1 THROUGH 6. SECOND CARD  USE 2 TO USES 1 THROUGH 6, ETC.
C  THE NEGATIVE VALUES INDICATE NEAGATIVE INCOMPATIBILITY
      00      01      02      03      04      04      00
      01      00      01      02      03      03      00
      02      01      00      01      02      02      00
      03      02      01      00      01      01      00
      04      03      02      01     -04      01      00
      04      03      02      01      01     -01      00
      00      00      00      00      00      00      00



C  PLANNED ALLOCATION OF USES TO LOCATIONS. ONE CARD PER LOCATION.
C  CARD ONE SHOWS 95 ACRES OF USE 1, 50 ACRES OF 3, AND 15 ACRES
C  OF 7 (VACANT). DISREGARD OTHER INFORMATION.
      160 95 95        50 50                    15 15
      180              180180
      140 35 35              100100         5  5
      160              160160
      160        50 50 55 55        40 40 15 15
      160              100100        40 40        20 20
      150               55 55 40 40                55 55
      175 65 65                      20 20  5  5 35 85
      155      100100                40 40        15 15
C  FOR EACH LOCATION THE PROXIMATE LOCATIONS AND THEIR RESPECTIVE
C  TRANSMISSION VALUES ARE RECORDED. THAT IS  CARD 1 (LOCATION 1)
C  SHOWS THAT LOCATION 2 IS ADJACENT AND HAS A TRANSMISSION
C  VALUE OF 1.0. LOCATION 3 IS ADJACENT BUT THERE IS 0.0 TRANSMISSION.
        2 10   3  0   4 10   5  0   6  0   7  0   8  0   9  0
        1 10   3 10   4  0   5 10   6  0   7  0   8  0   9  0
        1  0   2 10   4  0   5  0   6 10   7  0   8  0   9  0
        1 10   2  0   3  0   5 10   6  0   7 10   8  0   9  0
        1  0   2 10   3  0   4 10   6 10   7  0   8 10   9  0
        1  0   2  0   3 10   4  0   5 10   7  0   8  0   9 10
        1  0   2  0   3  0   4 10   5  0   6  0   8 10   9  0
        1  0   2  0   3  0   4  0   5 10   6  0   7 10   9 10
        1  0   2  0   3  0   4  0   5  0   6 10   7  0   8 10
```

A2. FLOCOST

The data required for this program are the inter-use trip rates, required use allocations, maximum interchange limits, minimum path flow costs and location size and use allocations. The only restriction of this data is that the order of the uses and locations be identical to that used in INCOMP.

The program calculates the inter-location flows for each trip type, and cancels opposing flows of the same type between two locations. In subroutine Label, the remaining flows are allocated at least cost. An assumed unit flow cost (EVN), $c_{ik(a)}$, is calculated in subroutine Rea from the shadow prices used in Label. In subroutine Alloc, each use in each location is assumed to be augmented, in turn. New flows of each type are calculated, and either added to the output flow matrix from Label, or allowed to cancel some of its opposing flows between the same locations, for the same trip type. The new flow system is brought into kilter, that is, the new flows are reallocated to give an optimal cost, if necessary. The difference in this optimal cost and the optimal cost determined by Label for the existing allocation is divided by the amount that the allocation was assumed to be increased. This result is then multiplied by two to approximate the effect of the new flows from and to the new use. The new figure forms the higher assumed unit flow cost (EV), c_{ik}'.

The output from this program is input to REALOC.

```
3291,GRECCO,T60,CM100000,P10.
RUN(S).
LGO.
7
C
C                                FLOCOST  TEST
C
C
      PROGRAM FLOCOST(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,
     1TAPE7=PUNCH)
C1  DIMENSIONS ARE FOR 6 USES AND 9 LOCATIONS
C2  VACANT USE IS LAST
C3  DATA CHECKS (IF DESIRED) AND VARIABLE USE AND LOCATION
C     DELIMITERS MUST BE ALTERED TO SUIT PARTICULAR APPLICATION.
C4  THIS PROGRAM HAS NOT BEEN WRITTEN FOR A SPECIFIC SYSTEM
C5  THE UNIT FLOW COSTS WERE TREATED AS INTEGER VALUES, FOR
C     COMPARISON PURPOSES. TO AVOID TRUNCATION THEY ARE MULTIPLIED
C     BY 10 AND LATER DIVIDED BY 10
      DIMENSION FL(6,6),SIZE(9),EV(9),EVN(9),F(9,9),
     1AL(6,9),ORL(9),OEK(9),RSIZE(6),IP(9),RMOV(6),
     2IPS(9),LAB(9),Q(9),IC(9,9),FS(9,9)
      COMMON K,L,LI,LJ,ORL,OEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,EVN,RSIZE,
     1RMOV,BMOV,NUSE,IPS,SIZE,FL,NULAB,FS
C  VARIABLE USE AND LOCATION DELIMITERS
      LI=9
      LJ=9
      NUSE=6
      NP=NUSE+1
C INPUT
      READ(5,1) FL,RSIZE,RMOV
    1 FORMAT(6F8.2)
      DO 500 I=1,LI
  500 READ(5,2)SIZE(I),(AL(K,I),K=1,NUSE)
    2 FORMAT (5X,F5.0,6(3X,F3.0))
    3 FORMAT(10F8.2)
      READ(5,4) IC
    4 FORMAT(9I8)
      WRITE(6,4)((IC(I,J),J=1,9),I=1,9)
      READ(5,7) FKL,FK
    7 FORMAT(2E20.7)
      WRITE(6,7) FKL,FK
C DATA CHECKS
      KT=0
      IF(FL(1,1)-1.00) 200,201,200
  201 KT=1
      IF(FL(6,4)-10.00) 200,202,200
  202 KT=2
      IF(SIZE(4)-160.) 200,203,200
  203 KT=3
      IF(RSIZE(5)-140.) 200,205,200
  205 KT=5
      IF(AL(3,5)-55.) 200,206,200
  206 KT=6
      IF(IC(4,7)-1) 200,207,200
  207 KT=7
      IF(RMOV(3)-100.) 200,208,200
  208 KT=8
      IF(BMOV(3)-25.) 200,209,200
  200 WRITE(6,10) KT
   10 FORMAT(1H ,13HDATA ERROR   ,I2)
      STOP
```

```
C
C  K DENOTES ORIGIN USE
C  L DENOTES DESTINATION USE
  209 TOTCD=0.
      DO 100 K=1,NUSE
      FK=0.
      DO 900 IQ=1,LI
      EV(IQ)=0.
  900 EVN(IQ)=0.
      DO 101 L=1,NUSE
      IF(K-L) 210,101,210
  210 IF(FL(K,L)) 211,101,211
C CALCULATE TRIP ORIGINS AND DESTINATIONS
  211 SUML=0.
  212 DO 102 I=1,LI
      ORL(I)=FL(K,L)*AL(K,I)
  102 SUML=SUML+ORL(I)
  214 DO 103 J=1,LJ
  103 DEK(J)=SUML*AL(L,J)/RSIZE(L)
C CONVERT NETWORK TO TRANSPO AND LABEL ORIGINS
  221 DO 110 I=1,LI
      LAB(I)=0
      Q(I)=0.
      IF(ORL(I)-.001) 110,252,252
  252 IF(ORL(I)-DEK(I)-0.1) 253,253,254
  253 DEK(I)=DEK(I)-ORL(I)
      ORL(I)=0.
      IF(DEK(I)-.001) 255,110,110
  254 ORL(I)=ORL(I)-DEK(I)
C LABEL ORIGINS
      LAB(I)=999
      Q(I)=ORL(I)
  255 DEK(I)=0.
  110 CONTINUE
C     INITIAL PRICE VECTOR
  222 DO 104 J=1,LJ
      IP(J)=0
      IF(DEK(J)-.001) 104,104,215
  215 IP(J)=999999
      DO 105 I=1,LI
      IF(ORL(I)-.001) 105,105,216
  216 IF(IC(I,J)-IP(J)) 217,105,217
  217 IP(J)=IC(I,J)
  105 CONTINUE
  104 CONTINUE
      CALL LABEL
      F1=FKL
      IF(K-9) 218,219,219
  218 CALL REA
  219 DO 107 I=1,LI
  107 IPS(I)=IP(I)
      IF(K-9) 220,223,223
  220 CALL ALLOC
  223 WRITE(6,21)(EV(I),I=1,10)
      WRITE(6,21)(EVN(I),I=1,10)
   21 FORMAT(17H EVALUATORS +AND-/1X,10E13.5)
      FK=FK+F1
      FKL=0.
  101 CONTINUE
      PUNCH 9,(EV(I),I=1,LI)
      PUNCH 9,(EVN(I),I=1,LI)
```

```
    9 FORMAT(1X,5E12.4)
  100 TOTCO=TOTCO+FK
      WRITE(6,22) FKL,FK
   22 FORMAT(8H FKL EQ ,E15.5,6HFK EQ ,E15.5)
      WRITE(6,23) TOTCO
   23 FORMAT(14H TOTCO EQUALS ,E20.7)
      STOP
      END
      SUBROUTINE REA
C  FORMS ASSUMED FLOW COST FOR DECREASED ALLOCATION USING
C  NODE OR SHADOW PRICES
      DIMENSION FL(5,6),SIZE(9),EV(9),EVN(9),F(9,9),
     1AL(6,9),ORL(9),DEK(9),RSIZE(6),IP(9),RMOV(6),
     1AL(6,9),ORL(9),DEK(9),RSIZE(6),IP(9),RMOV(6),
     2IPS(9),LAB(9),Q(9),IC(9,9),FS(9,9)
      COMMON K,L,LI,LJ,ORL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,EVN,RSIZE,
     1RMOV,BMOV,NUSE,IPS,SIZE,FL,NULAB,FS
      WRITE(6,1)
    1 FORMAT(12H ENTERED REA)
      DO 100 I=1,LI
      IF(AL(K,I)-.0001) 100,100,200
  200 DO 101 J=1,LJ
      IF(AL(L,J)-.0001) 101,101,201
  201 PRJ=IP(J)
      EVN(I)=EVN(I)-AL(L,J)*FL(K,L)*PRJ/10./(RSIZE(L)-AL(L,LJ+1))*2.
  101 CONTINUE
      PRI=IP(I)
      EVN(I)=EVN(I)+PRI/10.*FL(K,L)*2.
  100 CONTINUE
      WRITE(6,2) K,L,(EVN(I),I=1,9)
    2 FORMAT(18H FINISHED REA K EQ,I2,2X,4HL EQ,I2/(9E13.5))
      RETURN
      END
      SUBROUTINE ALLOC
C  FORMS ASSUMED UNIT FLOW COST FOR MAXIMAL ALLOCATION INCREASE
      DIMENSION FL(5,6),SIZE(9),EV(9),EVN(9),F(9,9),
     1AL(6,9),ORL(9),DEK(9),RSIZE(6),IP(9),RMOV(6),
     2IPS(9),LAB(9),Q(9),IC(9,9),FS(9,9)
      COMMON K,L,LI,LJ,ORL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,EVN,RSIZE,
     1RMOV,BMOV,NUSE,IPS,SIZE,FL,NULAB,FS
      WRITE(6,1)
    1 FORMAT(14H ENTERED ALLOC)
      IX=1
      DO 100 I=1,LI
C READ IN EXISTING ALLOCATIONS AND FLOWS
      DO 101 IK=1,LI
      IP(IK)=IPS(IK)
      LAB(IK)=0
      Q(IK)=0.
      ISAVE(IK)=0
      DO 101 JK=1,LJ
  101 F(IK,JK)=FS(IK,JK)
      ALL=RMOV(K)
      IF(ALL-SIZE(I)+AL(K,I)) 203,203,202
  202 ALL=SIZE(I)-AL(K,I)
      IF(ALL-.0001) 299,299,203
  299 EV(I)=EVN(I)
      GO TO 298
  203 AL(K,I)=AL(K,I)+ALL
      ORL(I)=ALL*FL(K,L)
      DO 102 J=1,LJ
```

```
      IF(I-J) 207,102,207
  207 IF(AL(L,J)-.0001) 102,102,208
  208 DEK(J)=ORL(I)*AL(L,J)/(RSIZE(L)-AL(L,LJ+1))
      IF(F(J,I)-.0001) 209,209,204
  204 IF(DEK(J)-F(J,I)) 205,205,206
  205 CF=IC(J,I)
      FKL=FKL-DEK(J)*CF/10.
      F(J,I)=F(J,I)-DEK(J)
      GO TO 102
  206 CF=IC(J,I)
      FKL=FKL-F(J,I)*CF/10.
      F(I,J)=DEK(J)-F(J,I)
      CF=IC(I,J)
      FKL=FKL+(DEK(J)-F(J,I))*CF/10.
      F(J,I)=0.
      GO TO 210
  209 F(I,J)=F(I,J)+DEK(J)
      CF=IC(I,J)
      FKL=FKL+DEK(J)*CF/10.
C KILTER CHECK
  210 IF(F(I,J)-.0001) 102,102,999
  999 IF(IC(I,J)+IP(I)-IP(J)) 211,102,212
C OKIL- NEGATIVE CIJ
  211 LAB(J)=I
      ITERM=I
      Q(J)=99999.
      ISAVE(IX)=J
      IX=IX+1
      JC=J
      GO TO 213
C OKIL- POSITIVE CIJ AND FLOW
  212 LAB(I)=-J
      ITERM=J
      Q(I)=F(I,J)
      ISAVE(IX)=I
      IX =IX+1
      IR=I
C LABEL COLUMNS
  213 N=0
  214 N=N+1
      IR=ISAVE(N)
      DO 103 JC=1,LJ
      IF(AL(L,JC)-.0001)103,215,215
  215 IF(LAB(JC))103,216,103
C ROUTE PRICE
  216 IF(IC(IR,JC)+IP(IR)-IP(JC)) 217,217,103
  217 LAB(JC)=IR
      Q(JC)=Q(IR)
  218 ISAVE(IX)=JC
      IX=IX+1
      IF(JC-ITERM)103,225,103
  103 CONTINUE
      JC=IR
      DO 104 IR=1,LI
       IF(AL(K,IR)-.0001)104,219,219
  219 IF(LAB(IR))104,220,104
C ROUTE PRICE
  220 IF(IC(IR,JC)+IP(IR)-IP(JC)) 104,221,221
  221 IF(F(IR,JC)-.0001)104,104,222
  222 LAB(IR)=-JC
      Q(IR)=F(IR,JC)
```

```
      IF(Q(IR)-Q(JC))224,224,223
  223 Q(IR)=Q(JC)
  224 ISAVE(IX)=IR
      IX=IX+1
      IF(IR-ITERM)104,226,104
  104 CONTINUE
      IF(ISAVE(N+1))214,250,214
C ALTER FLOW
  225 NJ=JC
      GO TO 228
  226 NJ=IR
  228 DEL=Q(NJ)
  229 IF(LAB(NJ)) 231,230,232
  230 WRITE(6,21)NJ
   21 FORMAT(14H TRACING ERROR,I4)
      STOP
  231 NI=IABS(LAB(NJ))
      F(NJ,NI)=F(NJ,NI)-DEL
      CF=IC(NJ,NI)
      FKL=FKL-DEL*CF/10.
      GO TO 233
  232 NI=LAB(NJ)
      F(NI,NJ)=F(NI,NJ)+DEL
      CF=IC(NI,NJ)
      FKL=FKL+DEL*CF/10.
  233 NJ=NI
      IF(NJ-ITERM) 229,234,229
  250 IDPR=999999
      IDNPR=-999999
  251 DO 107 IG=1,LI
      IF(AL(K,IG)-.0001) 107,252,252
  252 IF(LAB(IG))253,254,253
  253 DO 108 JO=1,LJ
      IF(AL(L,JO)-.0001) 108,108,255
  255 IF(LAB(JO)) 108,257,108
  257 IPRR=IC(IG,JO)+IP(IG)-IP(JO)
      IF(IPRR) 108,108,259
  259 IF(IPRR-IDPR) 270,108,108
  270 IDPR=IPRR
  108 CONTINUE
      GO TO 107
  254 DO 109 JO=1,LJ
      IF(AL(L,JO)-.0001) 109,109,256
  256 IF(LAB(JO)) 258,109,258
  258 IPRR=IC(IG,JO)+IP(IG)-IP(JO)
  273 IF(IPRR) 260,109,109
  260 IF(IPRR-IDNPR) 109,109,271
  271 IDNPR=IPRR
  109 CONTINUE
  107 CONTINUE
      IF(IDPR+IDNPR) 266,261,265
  265 IDPR=-IDNPR
      GO TO 266
  261 IF(IDPR-999999) 266,263,263
  263 WRITE(6,5) IDPR,IDNPR
    5 FORMAT(19H PRICING ERROR IDPR,I8,5HIDNPR,I8)
      STOP
  266 DO 110 IG=1,LI
      IF(AL(K,IG)-.0001) 267,267,268
  267 IF(AL(L,IG)-.0001) 110,110,268
  268 IF(LAB(IG)) 110,269,110
```

```
  269 IP(IG)=IP(IG)+IDPR
  110 CONTINUE
      WRITE(6,7)(IP(IT),IT=1,9)
    7 FORMAT(13H ALLOC PRICES,9I10)
  234 DO 105 IT=1,LI
      Q(IT)=0.
      LAB(IT)=0
  105 ISAVE(IT)=0
      IX=1
      GO TO 210
  102 CONTINUE
      EV(I)=EV(I)-(FKL-FI)/ALL*2.
      AL(K,I)=AL(K,I)-ALL
  298 FKL=FI
      WRITE(6,10)((F(IB,J),J=1,9),IB=1,9)
   10 FORMAT(27F4.0)
  100 CONTINUE
      WRITE(6,11)
   11 FORMAT(14H LEAVING ALLOC)
      RETURN
      END
      SUBROUTINE LABEL
C  ALLOCATES EXISTING ALLOCATION FLOWS AT LEAST COST, RECORDING
C  THAT COST
      DIMENSION FL(6,6),SIZE(9),EV(9),EVN(9),F(9,9),
     1AL(6,9),DRL(9),DEK(9),RSIZE(6),IP(9),RMOV(6),
     2IPS(9),LAB(9),Q(9),IC(9,9),FS(9,9)
      COMMON K,L,LI,LJ,DRL,DEK,IC,IP,F,LAB,J,FKL,FL,AL,EV,EVN,RSIZE,
     1RMOV,BMOV,NUSE,IPS,SIZE,FI,NULAB,FS
C INITIALIZE FLOWS
      DO 9 I=1,LI
      DO 9 J=1,LJ
    9 F(I,J)=0.
C     LABEL FLOW PATHS
   11 NULAB=0
      DO 12 I=1,LI
      IF(AL(K,I)-.0001) 12,12,13
   13 IF(LAB(I)) 20,19,20
   20 DO 18 J=1,LJ
      IF(AL(L,J)-.0001) 18,18,14
   14 IF(LAB(J)) 18,15,18
   15 IF(IC(I,J)+IP(I)-IP(J))16,16,18
   16 LAB(J)=I
      Q(J)=Q(I)
      IF(DEK(J)-.0001) 17,17,50
   17 NULAB = 1
   18 CONTINUE
      GO TO 12
   19 DO 21 J=1,LJ
      IF(AL(L,J)-.0001) 21,21,22
   22 IF(LAB(J)) 23,21,23
   23 IF(F(I,J)-.0001) 21,21,24
   24 LAB(I) = -J
      Q(I) = Q(J)
      IF (F(I,J).LT.Q(I)) Q(I) = F(I,J)
      IF(DEK(I)-0.1) 25,25,49
   25 NULAB=1
   21 CONTINUE
   12 CONTINUE
      IF (NULAB) 60,60,11
   60 IDPR=999999
```

```
      DO 71 I=1,LI
      IF(LAB(I))69,71,69
   69 DO 72 J=1,LJ
      IF(AL(L,J)-.0001)72,72,68
   68 IF(LAB(J))72,67,72
   67 IF(IC(I,J)+IP(I)-IP(J)-IOPR)96,72,72
   96 IOPR=IC(I,J)+IP(I)-IP(J)
   72 CONTINUE
   71 CONTINUE
      IF(IOPR-999999)80,74,74
   80 DO 73 I=1,LI
      IF(AL(K,I)-.0001) 81,81,83
   81 IF(AL(L,I)-.0001) 73,73,83
   83 IF(LAB(I))73,82,73
   82 IP(I)=IP(I)+IOPR
   73 CONTINUE
   76 WRITE(6,77)(IP(I),I=1,LI)
   77 FORMAT(11H NEW PRICES,9110)
      GO TO 11
   74 WRITE(6,75)K,L
   75 FORMAT(15H DPR EQUALS 999,2I4)
  100 WRITE (6,101) NJ
  101 FORMAT (1H ,44LAB(,I2,6H).EQ.0)
  102 WRITE (6,103)
  103 FORMAT (10H RLAB IS -)
      WRITE(6,4)(ORL(I),DEK(I),LAB(I),I=1,LI)
    4 FORMAT(3F10.1)
      WRITE(6,5)F
    5 FORMAT(9F8.1)
      WRITE(6,2)(LAB(I),I=1,9)
   10 STOP

      INCREMENT FLOW
   49 NJ=I
      NI=J
      J=NJ
      I=NI
      GO TO 51
   50 NI=I
      NJ = J
   51 IF(DEK(NJ).LT.Q(NJ)) Q(NJ)=DEK(NJ)
      DEL = Q(NJ)
      DEK(NJ) = DEK(NJ)-DEL
   52 IF(LAB(NJ)) 53,100,55
   53 F(NJ,NI) = F(NJ,NI)-DEL
      CF=IC(NJ,NI)
      FKL=FKL-DEL*CF/10.
      Q(NJ) = Q(NJ)-DEL
      IF(LAB(NI)-999) 54,56,54
   54 NIS=NI
      NJ  = NI
      NI  = IABS(LAB(NIS))
      GO TO 52
   55 F(NI,NJ) = F(NI,NJ)+DEL
      CF=IC(NI,NJ)
      FKL=FKL+DEL*CF/10.
      Q(NJ) = Q(NJ)-DEL
      IF(LAB(NI)-999) 54,56,54
   56 ORL(NI) = ORL(NI)-DEL
      Q(NI) = Q(NI) - DEL
      IF(ORL(NI).LT.0.1) ORL(NI)=0.
```

```
      WRITE (6,57) FKL
   57 FORMAT (4H FKL,F10.1)
   30 RLAB=0.
      DO 31 I=1,LI
      IF(DRL(I)-.0001) 33,33,32
   32 RLAB=1.
      GO TO 31
   33 Q(I) =0.
      LAB(I)=0
      DRL(I)=0.
   31 CONTINUE
      IF(RLAB) 102,34,11
   34 WRITE (6,3)F
    3 FORMAT(27F4.0)
  SAVE FLOW MATRIX FOR ALLOC
      DO 8 I=1,LI
      DO 8 J=1,LJ
    8 FS(I,J)=F(I,J)
    2 FORMAT (9I5)
      RETURN
      END
```

SAMPLE DATA

INTER- AND INTRA-USE FLOWS PER ACRE. CARD ONE DENOTES 1.00
TRIP PER DAY BETWEEN ONE ACRE OF USE 1 AND ONE ACRE OF
USE 1, 1.30 BETWEEN 1 AND 2, ETC.

100	130	100	800	600	11600	0
100	130	300	2000	2400	20000	0
100	130	90	350	800	10440	0
400	520	500	0	100	1000	0
300	390	600	200	0	880	0
600	780	700	800	700	1120	0
0	0	0	0	0	0	0

REQUIRED ACREAGE FOR EACH USE. THAT IS, 390.00 FOR USE 1,
300.000 FOR USE 2, ETC.

```
39000   30000   50000   14000   14000    2500   19000
```

MAXIMUM INTERCHANGE LIMITS. THAT IS, 100.00 FOR USE 1,
40.00 FOR USE 4,ETC.

```
10000   10000   10000    4000    8000    1000   20000
```

MINIMUM INTERCHANGE LIMITS. THAT IS, 25 FOR USE 1, ETC.

```
 2500    2500    2500    1000    2000     200       0
```

LOCATION SIZE AND USES IN ACRES . CARD ONE GIVES LOCATION 1
AS 160 ACRES OF WHICH 95 ARE USE 1 EXISTING, 95 ARE USE 1 PLANNED,
0 ARE USE 2 EXISTING, 0 ARE USE 2 PLANNED, 50 ARE USE 3
EXISTING, ETC.

```
    160 95 95       50 50                    15 15
    180            180180
    140 35 35           100100        5  5
    160            160160
    160       50 50 55 55       40 40 15 15
    160            100100       40 40       20 20
    150             55 55 40 40               55 55
    175 65 65                   20 20  5  5 85 85
    155      100100             40 40       15 15
    345195195150150
```

UNIT INTER-LOCATION FLOW COSTS IN DOLLARS PER YEAR PER DAILY
TRIP. CARD ONE GIVES $4 FOR TRAVEL FROM LOCATION 1 TO LOCATION 3.

```
   00      02      04      01      02      03      02      03      04      00
```

01	00	01	03	01	02	03	02	03	00
02	01	00	03	01	01	03	02	02	00
01	02	03	00	01	02	01	02	03	00
03	01	02	01	00	01	03	01	03	00
03	02	02	02	01	00	03	02	01	00
02	03	04	01	03	03	00	02	02	00
03	02	02	03	01	03	01	00	01	00
04	03	02	03	02	01	03	01	00	00

7

A3. REALOC

This program requires unit flow and incompatibility costs; location size, allocations, existing usage, and returns; and use requirements and maximum interchange limits. As in FLOCOST, the data must have the same order for use and location data as INCOMP does.

The program reduces the allocation of each use in each location, calculates a move evaluator and a capacity limit for each use in each location. The capacity limit is fixed by the level at which the move evaluator must be altered, or by the limit imposed on the interchange for that iteration. Initial shadow prices (dual variables) are determined and as much as possible of the non-vacant uses, which were freed previously, are allocated. New evaluators and capacities are then calculated, the shadow prices updated, and as much as possible of the remaining unallocated uses are reallocated. This last step is repeated until all uses except vacant have been reallocated. The uncommitted land, then, is allocated to vacant use.

Where multi-use activities are encountered, reallocation is permitted, for a given location, only to the use which increases the objective function the most. Since the use densities for a multi-use activity differ, both the amount of use and the unit use evaluator are considered in determining the best (better) use.

This program also combines the output incompatibility costs and flow costs from INCOMP and FLOCOST with the total location returns to determine a relative total cost for each iteration.

```
3291,GRECCO,T30,CM70000,P10.
RUN(S)
LGO.
7
C
C                                  REALOC  TEST
C
C
C1  REALLOCATES ACTIVITIES WITHIN INTERCHANGE LIMITS
C2  MULTI-USE ACTIVITIES ARE REALLOCATED TO THE BEST USE ONLY.
C3  DIMENSIONS ARE FOR 10 USES AND 10 LOCATIONS. CHANGE VARIABLE
C     USE AND LOCATION DELIMITERS AND MULTI-USE ACCOUNTING
C     FOR PARTICULAR APPLICATION
C4  THIS PROGRAM HAS NOT BEEN WRITTEN FOR A SPECIFIC SYSTEM
      PROGRAM REALOC(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,
     1TAPE6=OUTPUT,TAPE7=PUNCH)
      DIMENSION AL(10,10),ALI(10,10),ALM(10,10),ALP(10,10),
     1CAP(10,10),E(10,10),EV(10,10),          EVN(10,10),
     2EX(10,10),EXN(10,10),ORL(10),DEK(10),NLAB(10),LAB(10),
     3QN(10),Q(10),SIZE(10),IP(10),RMOV(10),TX(10,10),IPN(10),
     4RINC(10,10),RSIZE(10)
C  VARIABLE USE AND LOCATION DELIMITERS
      LI=9
      NUSE=6
      LJ=LI
      NP=NUSE+1
    1 FORMAT(5X,F5.0,14F3.0)
    2 FORMAT(10F8.2)
    3 FORMAT(9H1LOCATION,3X,28HINITIAL ALLOCATION OF USE NO///39
     1H NO  SIZE    1    2    3    4    5    6///)
    4 FORMAT(4X,12F4.1)
    5 FORMAT(1X,1P7E11.4)
    6 FORMAT(E20.7)
    7 FORMAT(9H1LOCATION,4X,26HREALLOCATION OF USE NUMBER////39
     1H NO  SIZE    1    2    3    4    5    6///)
    8 FORMAT(I3,F6.0,1X,6F5.0)
    9 FORMAT(1H1)
   10 FORMAT(1X,5E12.4/1X,3E12.4)
   11 FORMAT(10H IOPR =999)
   12 FORMAT(10F6.1)
   13 FORMAT(9F6.1)
   14 FORMAT(10I5)
   15 FORMAT(2I10)
   16 FORMAT (9F12.5)
   20 FORMAT(12F8.3)
C  INPUT
      READ(5,1)(SIZE(I),(ALI(K,I),AL(K,I),K=1,NP),I=1,LI)
      READ(5,2)RMOV
      READ(5,4)((EX(K,I),EXN(K,I),K=1,NUSE),I=1,LI)
      READ(5,5)((RINC(K,I),I=1,LI),K=1,NUSE)
      READ(5,6)TOTCO
      READ(5,6)TOT
      DO 40 K=1,NUSE
      READ(5,10)(EV(K,I),I=1,LI)
   40 READ(5,10)(EVN(K,I),I=1,LI)
C  CONVERT INCOMPATIBILITY AND RETURN TO ANNUAL CAPITAL
C  AND INTEREST COSTS
      DO 50 K=1,NUSE
      DO 51 I=1,LI
      EV(K,I)=-EV(K,I)
      EVN(K,I)=-EVN(K,I)
```

```
      IF(EVN(K,I).GT.EV(K,I))EVN(K,I)=EV(K,I)
      RINC(K,I)=RINC(K,I)*.07823
      IF(EXN(K,I))61,60,61
   60 EXN(K,I)=EX(K,I)
   61 EXN(K,I)=EXN(K,I)*.07823
      EX(K,I)=EX(K,I)*.07823
      IF(AL(K,I)-ALI(K,I))62,63,63
   62 XTOT=AL(K,I)*(EXN(K,I)-EX(K,I))
      GO TO 51
   63 XTOT=ALI(K,I)*(EXN(K,I)-EX(K,I))
   51 TOTCO =TOTCO-AL(K,I)*EX(K,I)-XTOT
   50 CONTINUE
      TOTCO=TOTCO+TOT
      WRITE(6,3)
      ICO=0
      DO 52 I=1,LI
      ICO=ICO+1
      IF(ICO-45)52,53,53
   53 WRITE(6,9)
      ICO=0
   52 WRITE(6,8)I,SIZE(I),(AL(K,I),K=1,NUSE)
      WRITE(6,9)
      WRITE(6,2)RMOV
      WRITE(6,20)((EX(K,I),EXN(K,I),K=1,NUSE),I=1,LI)
      WRITE(6,5)((RINC(K,I),I=1,LI),K=1,NUSE)
C  SET UP AS TRANSPO PROBLEM
      DO 100 I=1,LI
  100 DEK(I)=AL(NP,I)
      DO 101 K=1,NUSE
      ORL(K)=0.
      DO 102 I=1,LI
      ALP(K,I)=0.
      DEC=RMOV(K)*.5
      IF(AL(K,I)-DEC)200,201,201
  200 DEC=AL(K,I)
  201 ALM(K,I)=AL(K,I)-DEC
      ORL(K)=ORL(K)+DEC
      DEK(I)=DEK(I)+DEC
      TX(K,I)=AL(K,I)+RMOV(K)
      IF(TX(K,I)-SIZE(I))102,102,203
  203 TX(K,I)=SIZE(I)
  102 CONTINUE
  101 CONTINUE
      ORL(NP)=0.
      WRITE(6,12)ORL
C
C  ACCOUNT FOR MULTI-USE ACTIVITIES
      RATN=1.3
      ORL(1)=ORL(1)+RATN*ORL(2)
      ORL(2)=ORL(1)/RATN
      WRITE(6,12)ORL
      WRITE(6,12)DEK
      WRITE(6,13)((ALM(K,I),I=1,LI),K=1,NUSE)
      WRITE(6,13)((TX (K,I),I=1,LI),K=1,NUSE)
      ICH =0
C  BUILD EVALUATOR MATRIX
  212 DO 103 L=1,NUSE
      DO 103 J=1,LJ
      ALN=ALP(L,J)+ALM(L,J)
      E(L,J)=RINC(L,J)
      IF(ALN-ALI(L,J))204,205,205
```

```
  204 E(L,J)=E(L,J)-EXN(L,J)
      CAP(L,J)=ALI(L,J)-ALN
      IF(CAP(L,J)+ALN-TX(L,J))207,207,206
  205 E(L,J)=E(L,J)-EX(L,J)
  206 CAP(L,J)=TX(L,J)-ALN
  207 IF(AL(L,J)-ALN)209,209,208
  209 E(L,J)=E(L,J)+EV(L,J)
      GO TO 103
  208 E(L,J)=E(L,J)+EVN(L,J)
  210 IF(AL(L,J)-ALN-CAP(L,J))211,103,103
  211 CAP(L,J)=AL(L,J)-ALN
  103 CONTINUE
      WRITE(6,13)((E(K,I),I=1,LI),K=1,NUSE)
      WRITE(6,13)((CAP(K,I),I=1,LI),K=1,NUSE)
C
C  ACCOUNT FOR MULTI-USE ACTIVITIES
      DO 104 I=1,LI
      IF(E(1,I).GT.(E(2,I)/RATN))E(1,I)=E(1,I)+100.
      IF(E(1,I).LT.(E(2,I)/RATN))E(2,I)=E(2,I)+100.
  104 CONTINUE
      WRITE(6,13)((E(K,I),I=1,LI),K=1,2)
      IF(ICH.EQ.1) GO TO 219
C  INITIAL PRICE AND LABEL VECTORS
      NLAB(NP)=0
      DO 105 K=1,NUSE
      IPN(K)=0
      IF(ORL(K)-.0001)216,216,215
  215 NLAB(K)=999
      QN(K)=ORL(K)
      GO TO 105
  216 NLAB(K)=0
      QN(K)=0.
  105 CONTINUE
      DO 106 J=1,LJ
      LAB(J)=0
      Q(J)=0.
      IP(J)=0
      IF(DEK(J)-.0001)106,106,217
  217 IP(J)=999999
      DO 107 K=1,NUSE
      IE=E(K,J)*10.
      IF(IE-IP(J))218,107,107
  218 IP(J)=IE
  107 CONTINUE
  106 CONTINUE
      WRITE(6,14)NLAB
      WRITE(6,12)QN
      WRITE(6,14)IP
C  LABEL FLOW PATHS
  219 NULAB=0
      DO 108 K=1,NUSE
      IF(NLAB(K))220,230,220
  220 DO 109 J=1,LJ
      IF(LAB(J))109,221,109
  221 IE=E(K,J)*10.
      IF(IE+IPN(K)-IP(J))222,222,109
  222 Q(J)=QN(K)
      IF(CAP(K,J).LT.Q(J))Q(J)=CAP(K,J)
      IF(Q(J)-.0001)109,109,223
  223 IF(DEK(J)-.0001)224,224,234
  224 NULAB=1
```

```
      LAB(J)=K
  109 CONTINUE
      GO TO 108
  230 DO 110 J=1,LJ
      IF(LAB(J))231,110,231
  231 IF(ALP(K,J)-.0001)110,110,232
  232 IE=E(K,J)*10.
      IF(IE+IPN(K)-IP(J))110,233,233
  233 NLAB(K)=-J
      QN(K)=Q(J)
      IF(ALP(K,J).LT.QN(K))QN(K)=ALP(K,J)
      NULAB=1
  110 CONTINUE
  108 CONTINUE
      WRITE(6,14)NLAB
      WRITE(6,12)QN
      WRITE(6,14)LAB
      WRITE(6,12)Q
      IF(NULAB)250,250,219
C  INCREMENT ALLOCATION
  234 NI=K
      NJ=J
      WRITE(6,15)NI,NJ
      WRITE(6,14)NLAB
      WRITE(6,12)QN
      WRITE(6,14)LAB
      WRITE(6,12)Q
      ICH =0
  235 IF(DEK(NJ).LT.Q(NJ))Q(NJ)=DEK(NJ)
      DEL=Q(NJ)
      DEK(NJ)=DEK(NJ)-DEL
  236 ALP(NI,NJ)=ALP(NI,NJ)+DEL
      CAP(NI,NJ)=CAP(NI,NJ)-DEL
      Q(NJ)=Q(NJ)-DEL
      IF(NLAB(NI)-999)237,238,237
  237 NIS=NI
      NJ=NI
      NI=-NLAB(NIS)
      WRITE(6,15)NI,NJ
      ALP(NJ,NI)=ALP(NJ,NI)-DEL
      CAP(NJ,NI)=CAP(NJ,NI)+DEL
      QN(NJ)=QN(NJ)-DEL
      NIS=NI
      NJ=NI
      NI=LAB(NIS)
      WRITE(6,15)NI,NJ
      GO TO 236
  238 ORL(NI)=ORL(NI)-DEL
      QN(NI)=QN(NI)-DEL
      IF(NI-2)240,239,242
  240 ORL(2)=ORL(2)-DEL/RATN
      QN(2)=QN(2)-DEL/RATN
      GO TO 242
  239 ORL(1)=ORL(1)-DEL*RATN
      QN(1)=QN(1)-DEL*RATN
  242 ILAB=0
      DO 111 K=1,NJSE
      IF(ORL(K)-.0001)244,244,243
  243 ILAB=1
      QN(K)=ORL(K)
      NLAB(K)=999
```

```
      GO TO 111
  244 QN(K)=0.
      NLA8(K)=0
      DRL(K)=0.
  111 CONTINUE
      DO 112 J=1,LJ
      Q(J)=0.
  112 LA8(J)=0
      WRITE(6,12)DRL
      WRITE(6,12)DEK
      WRITE(6,14)LA8
      WRITE(6,14)NLA8
      WRITE(6,12)Q
      WRITE(6,12)QN
      IF(ILAB)245,245,219
  245 DO 113 K=1,NUSE
      RSIZE(K)=0.
      RMDV(K)=RMDV(K)*.5
      DO 113 J=1,LJ
      AL(K,J)=ALM(K,J)+ALP(K,J)
  113 RSIZE(K)=RSIZE(K)+AL(K,J)
      DO 114 I=1,LI
  114 AL (NP,I)=DEK(I)
      WRITE(6,7)
      ICO=0
      DO 115 I=1,LI
      ICO=ICO+1
      IF(ICO-45)115,115,246
  246 WRITE(6,9)
      ICO=0
  115 WRITE(6,8)I,SIZE(I),(AL(K,I),K=1,NUSE)
      WRITE(6,6)TOTCO
      WRITE(6,9)
      WRITE(6,12)RSIZE
      PUNCH 1,(SIZE(I), (ALI(K,I),AL(K,I),K=1,NP),I=1,LI)
      PUNCH 2,RSIZE
      STOP
  250 IF(ICH-1)2500,251,2500
 2500 ICH=1
      GO TO 212
C  REVISE PRICES
  251 ICH=0
      IDPR=999999
      DO 116 K=1,NUSE
      IF(NLA8(K))252,253,252
  252 DO 117 J=1,LJ
      IF(LA8(J))117,254,117
  254 IE=E(K,J)*10.
      IF(IE+IPN(K)-IP(J)-IDPR)255,117,117
  255 IF(IE+IPN(K)-IP(J))117,117,262
  262 IDPR=IE+IPN(K)-IP(J)
  117 CONTINUE
      GO TO 116
  253 DO 118 J=1,LJ
      IF(LA8(J))256,118,256
  256 IE=E(K,J)*10.
      IF(IE+IPN(K)-IP(J)+IDPR)118,118,257
  257 IF(IE+IPN(K)-IP(J))263,118,118
  263 IDPR=IP(J)-IPN(K)-IE
  118 CONTINUE
  116 CONTINUE
```

```
      IF(IDPR-999999)258,260,260
  258 DO 119 J=1,LJ
      IF(LAB(J))119,259,119
  259 IP(J)=IP(J)+IDPR
  119 CONTINUE
      DO 120 K=1,NUSE
      IF(NLAB(K))120,261,120
  261 IPN(K)=IPN(K)+IDPR
  120 CONTINUE
      WRITE(6,14)IP
      WRITE(6,14)IPN
      GO TO 219
  260 WRITE(6,11)
      STOP
      END
7
C                              SAMPLE DATA
C  LOCATION SIZE AND USES IN ACRES . CARD ONE GIVES LOCATION 1
C  AS 160 ACRES OF WHICH 95 ARE USE 1 EXISTING, 95 ARE USE 1 PLANNED,
C  0 ARE USE 2 EXISTING, 0 ARE USE 2 PLANNED, 50 ARE USE 3
C  EXISTING, ETC.
       160 95 95        50 50                      15 15
       180              180180
       140 35 35              100100         5  5
       150              160160
       160         50 50 55 55        40 40 15 15
       160              100100        40 40        20 20
       150               55 55 40 40                55 55
       175 65 65                      20 20  5  5 85 85
       155       100100               40 40        15 15
C  MAXIMUM INTERCHANGE LIMITS (SEE FLOCOST DATA).
     1000     1000     1000      500      400      200    20000
C  LOCATION RETURNS FOR CHANGE OF USE AND REALLOCATION OF USE(EX AND EXN).
C  CARD ONE REFERS TO LOCATION 1. EX =$109 PER ACRE (TOTAL,
C  NOT ANNUAL). SINCE COLUMNS 9-12 ARE BLANK,USE 1 DOES NOT EXIST IN
C  LOCATION 1 (NO EXISTING USES WERE SHOWN IN THE TEST SET).
      109      109      107      101      100      103        0
      107      107      106      101      100      103        0
      105      105      105      117      115      115        0
      107      107      106      102      110      104        0
      104      106      106      119      116      115        0
      105      105      105      117      113      115        0
      103      103      104      113      112      115        0
      103      103      104      115      114      115        0
      101      101      103      119      117      115        0
C  OUTPUT FROM INCOMP (RINC).
 15.6000E+0023.2000E+0020.8000E+0020.6000E+0030.4000E+0026.4000E+0013.0000E+00
 19.4000E+0014.4000E+0097.0000E-0115.9000E+0013.0000E+0013.2000E+0018.4000E+00
 16.2000E+0087.0000E-0112.3000E+0096.0000E-0138.0000E-0110.6000E+0052.0000E-01
 78.0000E-0184.0000E-0112.0000E+0044.0000E-0111.2000E+0088.0000E-0113.5000E+00
 16.7000E+0086.0000E-0115.2000E+0018.2000E+0014.0000E+0087.0000E-0114.5000E+00
 12.0000E+0023.2000E+0025.6000E+0014.5000E+0022.9000E+0024.4000E+0015.5000E+00
 13.9000E+0015.8000E+0011.3000E+0023.2000E+0027.4000E+0016.7500E+0024.8500E+00
 29.8000E+0022.2000E+0014.9500E+0021.2000E+0017.1500E+00
C  OUTPUT FROM FLOCOST (TOTCO).
       5.8475211E+03
C  OUTPUT FROM INCOMP (TOT)
         .7108749E+04
C  OUTPUT FROM FLOCOST (EV AND EVN)
  -7.4104E+00 -2.6398E+00 -3.3030E+00 -2.8893E+00 -7.8381E-01 -1.8312E+00
  -4.0573E+00 -3.3343E+00 -3.7128E+00
```

```
-7.5160E+00  0.          -2.5160E+00  0.           0.           0.
 0.          -3.3150E+00  0.
-7.7351E+00 -3.0838E+00 -3.4161E+00 -3.3049E+00 -8.2562E-01 -2.4980E+00
-6.5270E+00 -4.0951E+00 -7.8770E+00
 0.           0.           0.          0.          -2.7846E+00  0.
 0.           0.          -7.4646E+00
-1.2027E+01 -1.0584E+01 -3.3552E+00 -1.2584E+01 -2.8292E+00 -3.9914E+00
-7.2384E+00 -3.4098E+00 -2.6494E+00
-1.1184E+01 -1.0584E+01  0.          -1.2584E+01 -7.8447E-01 -6.9845E+00
-6.7845E+00  0.           0.
-1.6230E+01 -7.2346E+00 -1.8274E+01 -2.6950E+00 -1.2346E+00 -7.7277E+00
-1.7881E+01 -8.6318E+00 -8.4277E+00
 0.           0.          -2.5556E+01  0.           0.           0.
-1.8956E+01  0.           0.
-2.0076E+01 -1.2492E+01 -1.4812E+01 -1.1042E+01 -7.4656E+00 -1.0450E+01
-2.0380E+01 -1.0236E+01 -1.1036E+01
 0.           0.           0.          0.          -6.2759E+00 -1.5275E+01
 0.          -1.2676E+01 -1.0476E+01
-1.4140E+02 -1.4134E+02 -1.4135E+02 -1.0866E+02 -1.1107E+02 -8.6051E+01
-1.4125E+02 -8.3332E+01 -5.1619E+01
 0.           0.          -1.4521E+02  0.          -1.2601E+02  0.
 0.          -5.9054E+01  0.
7
```

A4. DUOFLO

This program is essentially the same as FLOCOST, but inter-location flows (F) are stored in one-half of the previous area by having the flow sign denote direction. Also the minimum path flow costs (IC) are input from magnetic tape. Both IC and the inter-location flows (FS), calculated from the existing allocation in subroutine Label, are stored on magnetic disks.

This program was written specifically for the Central Data Corporation 6500 computer system. For large data sets, it requires an excessive amount of computation time. Preliminary tests indicated that four or more hours per iteration of central processor time per iteration might be required.

```
3291,GRECCO,T200,CM150000,P10.
REQUEST(TAPE1,HY,E).MOUNT CSC TAPE624(JHRP28).RING OUT.
RUN(S)
LGO(LC,40000)
7
C
C                                  DUOFLO
C
C
C1  THIS PROGRAM IS ESSENTIALLY THE SAME AS FLOCOST. REFER TO IT
C     FOR DATA SETUP AND GENERAL COMMENTS. THIS WAS WRITTEN FOR
C     THE PURDUE CDC 6500. THE MAJOR MODIFICATION OF FLOCOST IS
C     STORAGE OF FLOWS IN A 'TRIANGULAR' MATRIX (F) WHERE THE
C     DIRECTION IS INDICATED BY SIGN
C2  DIMENSIONS HAVE BEEN SET UP FOR 10 USES AND 258 LOCATIONS
      PROGRAM DUOFLO(INPUT,OUTPUT,PUNCH,TAPE1,TAPE10,TAPE30,
     1TAPE5=INPUT,TAPE6=OUTPUT,TAPE7=PUNCH)
      DIMENSION FL(10,10),SIZE(258),EV(258),EVN(258),F(33153),
     1AL(10,258),ORL(258),DEK(258),RSIZE(10),IP(258),RMOV(10),BMOV(10),
     2IPS(258),LAB(258),Q(258),IC(258),ICA(258),ISAVE(258)
      COMMON M,N,NO,MUL,K,L,LI,LJ,ORL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,
     1EVN,RSIZE,RMOV,BMOV,NUSE,IPS,SIZE,FL,NULAB,II,ICA
      REAL MUL
C VACANT USE LAST
C  VARIABLE USE AND LOCATION DELIMITERS
      LI=258
      LJ=258
      NUSE=9
      NP=NUSE+1
      II=30
C INPUT
      READ(5,1) FL,RSIZE,RMOV,BMOV
    1 FORMAT(10F8.2)
      WRITE(6,1)FL,RSIZE,RMOV,BMOV
      DO 500 I=1,LI
  500 READ(5,2)SIZE(I),(AL(K,I),K=1,10)
    2 FORMAT((5X,F5.0,10(3X,F3.0)))
    3 FORMAT(10F8.2)
      REWIND 1
      REWIND 10
      DO 600 I=1,LI
      READ (1)IC
  600 WRITE(10)IC
      WRITE(6,55555)IC
55555 FORMAT(2014)
C
C N DENOTES ORIGIN USE
C L DENOTES DESTINATION USE
  209 TOTCO=0.
      DO 100 K=1,NUSE
      FK=0.
      DO 900 IQ=1,LI
      EV(IQ)=0.
  900 EVN(IQ)=0.
      DO 101 L=1,NUSE
      FKL=0.
      IF(K-L) 210,101,210
  210 IF(FL(K,L)) 211,101,211
C CALCULATE TRIP ORIGINS AND DESTINATIONS
  211 SUML=0.
C  DIVERT ALL PURDUE ORIGINS TO LOCATION 143 (MAIN CAMPUS)
      IF(K-9) 212,213,212
  212 DO 102 I=1,LI
      ORL(I)=FL(K,L)*AL(K,I)
  102 SUML=SUML+ORL(I)
```

```
C  DIVERT ALL PURDUE DESTINATIONS TO LOCATION 143 (MAIN CAMPUS)
      IF(L-9) 214,298,214
  298 DO 108 J=1,LJ
  108 DEK(J)=0.
      DEK(143)=SUML
      GO TO 221
  213 DO 109 I=1,LI
  109 ORL(I)=0.
      ORL(143)=FL(K,L)*AL(K,143)
  214 DO 103 J=1,LJ
  103 DEK(J)=SUML*AL(L,J)/RSIZE(L)
  221 WRITE(6,51)
   51 FORMAT(1H ,11HENTERED CON)
C CONVERT NETWORK TO TRANSPO AND LABEL ORIGINS
      DO 110 I=1,LI
      LAB(I)=0
      Q(I)=0.
      IF(ORL(I)-.001) 110,252,252
  252 IF(ORL(I)-DEK(I)-0.1) 253,253,254
  253 DEK(I)=DEK(I)-ORL(I)
      ORL(I)=0.
      IF(DEK(I)-.001) 255,110,110
  254 ORL(I)=ORL(I)-DEK(I)
C LABEL ORIGINS
      LAB(I)=999
      Q(I)=ORL(I)
  255 DEK(I)=0.
  110 CONTINUE
C     INITIAL PRICE VECTOR
      REWIND 10
  222 DO 104 J=1,LJ
      READ(10) IC
      IPS(J)=0
      IF(DEK(J)-.001) 104,104,215
  215 IPS(J)=999999
      DO 105 I=1,LI
      IF(ORL(I)-.001) 105,105,216
  216 IF(IC(I)-IPS(J))217,105,217
  217 IPS(J)=IC(I)
  105 CONTINUE
  104 CONTINUE
      CALL LABEL
      F1=FKL
      WRITE(6,23) FKL
   23 FORMAT(8H FKL EQ ,E15.5)
C  EVALUATORS NOT NEEDED FOR PURDUE USE (FIXED LOCATIONS)
      IF(K-9) 218,219,219
  218 CALL REA
      CALL ALLOC
  223 WRITE(6,21)(EV(I),I=1,10)
      WRITE(6,21)(EVN(I),I=1,10)
   21 FORMAT(17H EVALUATORS +AND-/1X,10E13.5)
  219 FK=FK+F1
  101 CONTINUE
      PUNCH 9,(EV(I),I=1,LI)
      PUNCH 9,(EVN(I),I=1,LI)
    9 FORMAT(1X,1P7E11.4)
  100 TOTCO=TOTCO+FK
      WRITE(6,22) FKL,FK
   22 FORMAT(8H FKL EQ ,E15.5,6HFK EQ ,E15.5)
      WRITE(6,24) TOTCO
   24 FORMAT(14H TOTCO EQUALS ,E 20.7)
      STOP
      END
```

```
      SUBROUTINE REA
      DIMENSION FL(10,10),SIZE(258),EV(258),EVN(258),F(33153),
     1AL(10,258),DRL(258),DEK(258),RSIZE(10),IP(258),RMOV(10),BMOV(10),
     2IPS(258),LAB(258),Q(258),IC(258),ICA(258),ISAVE(258)
      COMMON M,N,NO,MUL,K,L,LI,LJ,DRL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,
     1EVN,RSIZE,RMOV,BMOV,NUSE,IPS,SIZE,F1,NULAB,II,ICA
      REAL MUL
      WRITE(6,1)
    1 FORMAT(12H ENTERED REA)
C FORMS REALLOCATION MATRIX USING NODE PRICES FOR FLOW COSTS
      DO 100 I=1,LI
      IF(AL(K,I)-.0001) 100,100,200
  200 DO 101 J=1,LJ
      IF(AL(L,J)-.0001) 101,101,201
  201 PRJ=IP(J)
      EVN(I)=EVN(I)-AL(L,J)*FL(K,L)*PRJ/RSIZE(L)*2.
  101 CONTINUE
      PRI=IP(I)
      EVN(I)=EVN(I)+PRI*FL(K,L)*2.
  100 CONTINUE
      WRITE(6,2) K,L,(EVN(I),I=1,9)
    2 FORMAT(18H FINISHED REA K EQ,I2,2X,4HL EQ,I2/(9E13.5))
      RETURN
      END
      SUBROUTINE ALLOC
      DIMENSION FL(10,10),SIZE(258),EV(258),EVN(258),F(33153),
     1AL(10,258),DRL(258),DEK(258),RSIZE(10),IP(258),RMOV(10),BMOV(10),
     2IPS(258),LAB(258),Q(258),IC(258),ICA(258),ISAVE(258)
      COMMON M,N,NO,MUL,K,L,LI,LJ,DRL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,
     1EVN,RSIZE,RMOV,BMOV,NUSE,IPS,SIZE,F1,NULAB,II,ICA
      REAL MUL
      WRITE(6,1)
    1 FORMAT(14H ENTERED ALLOC)
      IX=1
      DO 100 I=1,LI
C READ IN EXISTING ALLOCATIONS AND FLOWS
      REWIND II
      READ(II)F
      DO 101 IK=1,LI
      IP(IK)=IPS(IK)
      LAB(IK)=0
      Q(IK)=0.
  101 ISAVE(IK)=0
      ALL=RMOV(K)
      IF(ALL-SIZE(I)+AL(K,I)) 203,203,202
  202 ALL=SIZE(I)-AL(K,I)
      IF(ALL-.0001) 299,299,203
  299 EV(I)=EVN(I)
      GO TO 298
  203 AL(K,I)=AL(K,I)+ALL
      DRL(I)=ALL*FL(K,L)
      REWIND 10
      DO 1020 J=1,LJ
```

```
      READ(10)IC
      IF(I-J) 207,102,207
  207 IF(AL(L,J)-.0001) 102,102,208
  208 DEK(J)=ORL(I)*AL(L,J)/RSIZE(L)
      CF=IC(I)
      M=J
      N=I
      CALL CON
      IF(F(NO)*MJL-.0001)209,209,204
  204 IF(DEK(J)-F(NJ)*MJL)206,206,205
  205 FKL=FKL+(DEK(J)-F(NO)*MJL)*CF
      FKL=FKL-F(NO)*MJL*CF
      GO TO 300
  206 FKL=FKL-DEK(J)*CF
      GO TO 300
  209 FKL=FKL+DEK(J)*CF
  300 F(NO)=F(NO)-DEK(J)*MJL
C KILTER CHECK
  210 IF(F(NO)*MJL+.0001)999,102,102
  999 IF(IC(I)+IP(I)-IP(J)) 211,102,212
C OKIL- NEGATIVE CIJ
  211 LAB(J)=I
      ITERM=I
      Q(J)=99999.
      ISAVE(IX)=J
      IX=IX+1
      JC=J
      GO TO 213
C OKIL- POSITIVE CIJ AND FLOW
  212 LAB(I)=-J
      ITERM=J
      Q(I)=-F(NO)*MJL
      ISAVE(IX)=I
      IX =IX+1
C LABEL COLUMNS
  213 NQ=0
  214 NQ=NQ+1
      IR=ISAVE(NQ)
      REWIND 10
      DO 600 IA=1,IR
  600 READ(10)IC
      DO 103 JC=1,LJ
      IF(AL(L,JC)-.0001)103,215,215
  215 IF(LAB(JC))103,216,103
C ROUTE PRICE
  216 IF(IC(JC)+IP(IR)-IP(JC)) 217,217,103
  217 LAB(JC)=IR
      Q(JC)=Q(IR)
  218 ISAVE(IX)=JC
      IX=IX+1
      IF(JC-ITERM)103,225,103
  103 CONTINUE
      JC=IR
      DO 104 IR=1,LI
       IF(AL(K,IR)-.0001)104,219,219
  219 IF(LAB(IR))104,220,104
C ROUTE PRICE
  220 IF(IC(IR)+IP(IR)-IP(JC)) 104,221,221
  221 M=IR
      N=JC
      CALL CON
```

```
      IF(F(NO)*MJL-.0001)104,104,222
  222 LAB(IR)=-JC
      Q(IR)=F(NO)*MJL
      IF(Q(IR)-Q(JC))224,224,223
  223 Q(IR)=Q(JC)
  224 ISAVE(IX)=IR
      IX=IX+1
      IF(IR-ITERM)104,226,104
  104 CONTINUE
      IF(ISAVE(NQ+1))214,250,214
C ALTER FLOW
  225 NJ=JC
      GO TO 228
  226 NJ=IR
  228 WRITE(6,2)(IT,LAB(IT),Q(IT),IT=1,9)
    2 FORMAT(11H FLOW DELTA,9(213,F5.1))
      DEL=Q(NJ)
  229 IF(LAB(NJ)) 231,230,232
  230 WRITE(6,21)NJ
   21 FORMAT(14H TRACING ERROR,I4)
      STOP
  231 NI=IABS(LAB(NJ))
      REWIND 10
      DO 601 IA=1,NJ
  601 READ(10) IC
      CF=IC(NI)
      M=NJ
      N=NI
      CALL CON
      F(NO)=F(NO)-DEL*MJL
  700 FKL=FKL-DEL*CF
      GO TO 233
  232 NI=LAB(NJ)
      REWIND 10
      DO 603 IA=1,NI
  603 READ(10) IC
      M=NI
      N=NJ
      CALL CON
      F(NO)=F(NO)+DEL*MJL
 7009 CF=IC(NJ)
  701 FKL=FKL+DEL*CF
  233 NJ=NI
      IF(NJ-ITERM) 229,234,229
  250 WRITE(6,4)(IW,LAB(IW),IP(IW),IW=1,9)
    4 FORMAT(15H REVISE PRICES/,9(213,I6))
      IDPR=999999
      IDNPR=-999999
      REWIND 10
  251 DO 107 IG=1,LI
      READ(10) IC
      IF(AL(K,IG)-.0001) 107,252,252
  252 IF(LAB(IG))253,254,253
  253 DO 108 JO=1,LJ
      IF(AL(L,JO)-.0001) 108,108,255
  255 IF(LAB(JO)) 108,257,108
  257 IPRR=IC(JO)+IP(IG)-IP(JO)
      IF(IPRR) 108,108,259
  259 IF(IPRR-IDPR) 270,108,108
  270 IDPR=IPRR
  108 CONTINUE
```

```
      GO TO 107
  254 DO 109 JO=1,LJ
      IF(AL(L,JO)-.0001) 109,109,256
  256 IF(LAB(JO)) 258,109,258
  258 IPRR=IC(JO)+IP(IG)-IP(JJ)
  273 IF(IPRR) 250,109,109
  260 IF(IPRR-IDNPR) 109,109,271
  271 IDNPR=IPRR
  109 CONTINUE
  107 CONTINUE
      IF(IDPR+IDNPR) 266,261,265
  265 IDPR=-IDNPR
      GO TO 266
  261 IF(IDPR-999999) 266,263,263
  263 WRITE(6,5) IDPR,IDNPR
    5 FORMAT(19H PRICING ERROR IDPR,I8,5HIDNPR,I8)
      STOP
  266 DO 110 IG=1,LI
      IF(AL(K,IG)-.0001) 267,267,268
  267 IF(AL(L,IG)-.0001) 110,110,268
  268 IF(LAB(IG)) 110,269,110
  269 IP(IG)=IP(IG)+IDPR
  110 CONTINUE
  234 DO 105 IT=1,LI
      Q(IT)=0.
      LAB(IT)=0
  105 ISAVE(IT)=0
      IX=I
      REWIND 10
      DO 8001 IT=1,J
 8001 READ (10)IC
      M=J
      N=I
      CALL CON
      GO TO 210
  102 CONTINUE
 1020 CONTINUE
      EV(I)=EV(I)-(FKL-F1)/ALL*2.
      AL(K,I)=AL(K,I)-ALL
  298 WRITE(6,9) K,I,EV(I),FKL,FI,AL(K,I)
    9 FORMAT(21H ALLOC AND FLOW COSTS,2I4,3E15.7,F10.0)
      FKL=FI
  100 CONTINUE
      WRITE(6,11)
   11 FORMAT(14H LEAVING ALLOC)
      RETURN
      END
      SUBROUTINE LABEL
      DIMENSION FL(10,10),SIZE(258),EV(258),EVN(258),F(33153),
     1AL(10,258),ORL(258),DEK(258),RSIZE(10),IP(258),RMOV(10),BMOV(10),
     2IPS(258),LAB(258),Q(258),IC(258),ICA(258),ISAVE(258)
      COMMON M,N,NO,MUL,K,L,LI,LJ,ORL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,
     1EVN,RSIZE,RMOV,BMOV,NUSE,IPS,SIZE,FI,NULAB,II,ICA
      REAL MUL
 1000 WRITE(6,1)
    1 FORMAT (1HO, 13HENTERED LABEL)
C INITIALIZE FLOWS
      DO 9 I=1,33153
    9 F(I)=0.
C     LABEL FLOW PATHS
   11 NULAB=0
```

```
      REWIND 10
      DO 12 I=1,LI
      READ(10) IC
      IF(AL(K,I)-.0001) 12,12,13
   13 IF(LAB(I)) 20,19,20
   20 DO 18 J=1,LJ
      IF(AL(L,J)-.0001) 18,18,14
   14 IF(LAB(J)) 18,15,18
   15 IF(IC(J)+IPS(I)-IPS(J))16,16,18
   16 LAB(J)=I
      Q(J)=Q(I)
      IF(DEK(J)-.0001) 17,17,50
   17 NULAB = 1
   18 CONTINUE
      GO TO 12
   19 DO 21 J=1,LJ
      IF(AL(L,J)-.0001) 21,21,22
   22 IF(LAB(J)) 23,21,23
   23 M=I
      N=J
      CALL CON
      IF(F(NO)*MUL-.0001)21,21,24
   24 LAB(I) = -J
      Q(I) = Q(J)
      IF(F(NO)*MUL.LT.Q(I))Q(I)=F(NO)*MUL
      IF(DEK(I)-0.1) 25,25,49
   25 NULAB=1
   21 CONTINUE
   12 CONTINUE
      IF (NULAB) 60,60,11
C  REVISE SHADOW PRICES
C
   60 IDPR=999999
      REWIND 10
      DO 71 I=1,LI
      READ(10) IC
      IF(LAB(I))69,71,69
   69 DO 72 J=1,LJ
      IF(AL(L,J)-.0001)72,72,68
   68 IF(LAB(J))72,67,72
   67 IF(IC(J)+IPS(I)-IPS(J)-IDPR)96,72,72
   96 IF(IC(J)+IPS(I)-IPS(J))72,72,200
  200 IDPR=IC(J)+IPS(I)-IPS(J)
   72 CONTINUE
   71 CONTINUE
      IF(IDPR-999999)80,74,74
   80 DO 73 I=1,LI
      IF(AL(K,I)-.0001) 81,81,83
   81 IF(AL(L,I)-.0001) 73,73,83
   83 IF(LAB(I))73,82,73
   82 IPS(I)=IPS(I)+IDPR
   73 CONTINUE
   76 WRITE(6,77)(IPS(I),I=1,LI)
   77 FORMAT(11H NEW PRICES,9I10)
      GO TO 11
   74 WRITE(6,75)K,L
   75 FORMAT(15H DPR EQUALS 999,2I4)
  100 WRITE (6,101) NJ
  101 FORMAT (1H ,4HLAB(,I2,6H).EQ.0)
  102 WRITE (6,103)
  103 FORMAT (10H RLAB IS -)
```

```
      WRITE(6,4)(ORL(I),DEK(I),LAB(I),I=1,LI)
    4 FORMAT(1X,2F10.1,I10)
      WRITE(6,2)(LAB(I),I=1,9)
    2 FORMAT(1X,9I13)
   10 STOP
C
C     INCREMENT FLOW
   49 NJ=I
      NI=J
      J=NJ
      I=NI
      GO TO 58
   50 NI=I
      NJ = J
   58 WRITE(6,104) NI,NJ,LAB(NJ)
  104 FORMAT(3I4)
   51 IF(DEK(NJ).LT.Q(NJ)) Q(NJ)=DEK(NJ)
      DEL = Q(NJ)
      DEK(NJ) = DEK(NJ)-DEL
   52 IF(LAB(NJ)) 53,100,55
   53 REWIND 10
      DO 602 I=1,NJ
  602 READ(10)IC
      CF=IC(NI)
      M=NJ
      N=NI
      CALL CON
      F(NO)=F(NO)-DEL*MJL
      FKL=FKL-DEL*CF
      Q(NJ) = Q(NJ)-DEL
      IF(LAB(NI)-999) 54,56,54
   54 NIS=NI
      NJ  = NI
      NI = IABS(LAB(NIS))
      WRITE(6,104) NI,NJ,LAB(NJ)
      GO TO 52
   55 REWIND 10
      DO 601 I=1,NI
  601 READ(10)IC
      M=NI
      N=NJ
      CALL CON
      F(NO)=F(NO)+DEL*MJL
      CF=IC(NJ)
      FKL=FKL+DEL*CF
      Q(NJ) = Q(NJ)-DEL
      IF(LAB(NI)-999) 54,56,54
   56 ORL(NI) = ORL(NI)-DEL
      Q(NI) = Q(NI) - DEL
      IF(ORL(NI).LT.0.1) ORL(NI)=0.
   30 RLAB=0.
      DO 31 I=1,LI
      IF(ORL(I)-.0001) 33,33,32
   32 RLAB=1.
      GO TO 31
   33 Q(I) =0.
      LAB(I)=0
      ORL(I)=0.
   31 CONTINUE
      IF(RLAB) 34,34,11
   34 REWIND 11
```

```
      WRITE(11)F
      WRITE (6,35)
   35 FORMAT (1H0, 13HLEAVING LABEL)
      RETURN
      END
      SUBROUTINE CON
      COMMON M,N,ND,MUL
      REAL MUL
      IF(M-N) 100,400,101
  100 ND=(N-1)*(N-2)/2+M
      MUL=-1.
  300 RETURN
  101 ND=(M-1)*(M-2)/2+N
      MUL=1.
      RETURN
  400 MUL = 0.
      RETURN
      END
7
C  SAMPLE DATA HAVE BEEN OMITTED. THESE ARE SIMILAR TO FLOCOST,
C  EXCEPT THAT THE MINIMUM COST OF FLOW MATRIX (IC) IS READ
C  IN BINARY FORM FROM TAPE TO DISK FOR RAPID ACCESS
```

A5. DUAL1

This program is a modification of FLOCOST which aggregates location allocations into district allocations and then calculates the inter-district flow costs and their contribution to the assumed unit flow costs.

In addition to the FLOCOST data types, it requires a list of locations by district (LIS) and the number of usable locations in each district.

```
3291,GRECCO,T200,CM70000,P10.
RUN(S)
LGO(LC,40000)
7
C
C                                  DUAL1
C
C
C1   THIS PROGRAM CALCULATES ALL INTER-DISTRICT FLOW COSTS AND THEIR
C     CONTRIBUTIONS TO THE FLOW COST EVALUATORS
C2   DIMENSIONS HAVE BEEN SET FOR 21 DISTRICTS
       PROGRAM DUAL1(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,TAPE6=OUTPUT,
      1TAPE7=PUNCH)
       DIMENSION FL(10,10),SIZE(258),EV(21),EVN(21),F(21,21),
      1TAL(9,258),ORL(21),OEK(21),RSIZE(10),IP(21),RMOV(10),
      2IPS(21),LAB(21),Q(21),IC(21,21),FS(21,21),AL(9,21),
      3 NQ(21),ISAVE(21),LIS(20)
       COMMON K,L,LI,LJ,ORL,OEK,IC,FKL,FL,AL,EV,EVN,RSIZE,TAL,
      1RMOV,NUSE,IPS,SIZE,F1,NJLAB,FS,LAB,Q
C VACANT USE LAST
     1 FORMAT(10F8.2)
     2 FORMAT(10X,9(3X,F3.0))
     3 FORMAT(20I4)
     4 FORMAT(2I4)
     5 FORMAT(21I3)
     6 FORMAT(I5,9F7.0)
     7 FORMAT(3H EV,1X,10E12.4)
     8 FORMAT(4H EVN,1X,10E12.4)
C INPUT
       READ(5,4)LI,NJSE
C   LI DENOTES  NUMBER OF DISTRICTS
C   NUSE DENOTES NUMBER OF USES
       NP=NUSE+1
       LJ=LI
       READ(5,1) FL,RSIZE,RMOV
       DO 500 I=1,258
C   TAL(K,I) DENOTES THE ALLOCATION OF USE K TO LOCATION I
  500 READ(5,2)(TAL(K,I),K=1,NUSE)
C   IC DENOTES THE INTER-DISTRICT MINIMUM FLOW COST MATRIX
       READ(5,3)IC
C   NQ(I) DENOTES THE NUMBER OF LOCATIONS IN DISTRICT I
       READ(5,5)NQ
       DO 50 K=1,NUSE
       DO 50 I=1,LI
   50 AL(K,I)=0.
C   AL(K,I) DENOTES THE ALLOCATION OF USE K TO DISTRICT I
       DO 51 I=1,LI
       NPQ=NQ(I)
C   LIS IS A LIST OF LOCATIONS IN DISTRICT I
       READ(5,3)LIS
       DO 52 J=1,NPQ
       JI=LIS(J)
       DO 53 K=1,NUSE
   53 AL(K,I)=AL(K,I)+TAL(K,JI)
   52 CONTINUE
   51 CONTINUE
       DO 54 I=1,LI
   54 WRITE(6,6)I,(AL(K,I),K=1,NUSE)
C K DENOTES ORIGIN USE
C L DENOTES DESTINATION USE
  209 TOTCO=0.
```

```
      DO 100 K=1,NUSE
      FK=0.
      DO 900 IQ=1,LI
      EV(IQ)=0.
  900 EVN(IQ)=0.
      DO 101 L=1,NUSE
      FKL=0.
      IF(K-L) 210,101,210
C  DISREGARD INSIGNIFICANT FLOWS
  210 IF(FL(K,L)-.2)101,101,211
C CALCULATE TRIP ORIGINS AND DESTINATIONS
  211 SUML=0.
C  DIVERT ALL PURDUE ORIGINS TO LOCATION 143
      IF(K-9) 212,213,212
  212 DO 102 I=1,LI
      ORL(I)=FL(K,L)*AL(K,I)
  102 SUML=SUML+ORL(I)
C  DIVERT ALL PURDUE DESTINATIONS TO LOCATION 143
      IF(L-9) 214,298,214
  298 DO 108 J=1,LJ
  108 DEK(J)=0.
      DEK(6)=SUML
      GO TO 221
  213 DO 109 I=1,LI
  109 ORL(I)=0.
      ORL(6)=FL(K,L)*TAL(K,122)
  214 DO 103 J=1,LJ
  103 DEK(J)=SUML*AL(L,J)/RSIZE(L)
C CONVERT NETWORK TO TRANSPO AND LABEL ORIGINS
  221 DO 110 I=1,LI
      LAB(I)=0
      Q(I)=0.
      IF(ORL(I)-.001) 110,252,252
  252 IF(ORL(I)-DEK(I)-0.1) 253,253,254
  253 DEK(I)=DEK(I)-ORL(I)
      ORL(I)=0.
      IF(DEK(I)-.001) 255,110,110
  254 ORL(I)=ORL(I)-DEK(I)
C LABEL ORIGINS
      LAB(I)=999
      Q(I)=ORL(I)
  255 DEK(I)=0.
  110 CONTINUE
C     INITIAL PRICE VECTOR
  222 DO 104 J=1,LJ
      IPS(J)=0
      IF(DEK(J)-.001) 104,104,215
  215 IPS(J)=999999
      DO 105 I=1,LI
      IF(ORL(I)-.001) 105,105,216
  216 IF(IC(I,J)-IPS(J))217,105,217
  217 IPS(J)=IC(I,J)
  105 CONTINUE
  104 CONTINUE
      CALL LABEL
      F1=FKL
C  FOR PURDUE(FIXED LOCATIONS) DELETE EVALUATOR FORMATION
      IF(K-9) 218,219,219
  218 CALL REA
  220 CALL ALLOC
  223 WRITE(6,21)(EV(I),I=1,10)
```

```
      WRITE(6,21)(EVN(I),I=1,10)
   21 FORMAT(17H EVALUATORS +ANO-/1X,10E13.5)
  219 FK=FK+F1
  101 CONTINUE
      PUNCH 9,(EV(I),I=1,LI)
      PUNCH 9,(EVN(I),I=1,LI)
    9 FORMAT(1X,5E12.4)
      TOTCO=TOTCO+FK
  100 WRITE(6,23)TOTCO
      WRITE(6,22) FKL,FK
   22 FORMAT(8H FKL EQ ,E15.5,6HFK EQ ,E15.5)
      WRITE(6,23) TOTCO
   23 FORMAT(14H TOTCO EQUALS ,E20.7)
      STOP
      END
$IBFTC SUBP1
      SUBROUTINE REA
      DIMENSION FL(10,10),SIZE(258),EV(21),EVN(21),F(21,21),
     1TAL(9,258),ORL(21),DEK(21),RSIZE(10),IP(21),RMOV(10),
     2IPS(21),LAB(21),Q(21),IC(21,21),FS(21,21),AL(9,21),
     3 NQ(21),ISAVE(21),LIS(20)
      COMMON K,L,LI,LJ,ORL,DEK,IC,FKL,FL,AL,EV,EVN,RSIZE,TAL,
     1RMOV,NUSE,IPS,SIZE,F1,NJLAB,FS,LAB,Q
C  FORMS UNIT FLOW COST(CIKA) USING NODE PRICES
      DO 100 I=1,LI
      IF(AL(K,I)-.0001) 100,100,200
  200 DO 101 J=1,LJ
      IF(AL(L,J)-.0001) 101,101,201
  201 PRJ=IPS(J)
      EVN(I)=EVN(I)-AL(L,J)*FL(K,L)*PRJ/RSIZE(L)*2.
  101 CONTINUE
      PRI=IPS(I)
      EVN(I)=EVN(I)+PRI*FL(K,L)*2.
  100 CONTINUE
      WRITE(6,2) K,L,(EVN(I),I=1,LI)
    2 FORMAT(1X,10E13.5)
      RETURN
      END
$IBFTC SUBP2
      SUBROUTINE ALLOC
      DIMENSION FL(10,10),SIZE(258),EV(21),EVN(21),F(21,21),
     1TAL(9,258),ORL(21),DEK(21),RSIZE(10),IP(21),RMOV(10),
     2IPS(21),LAB(21),Q(21),IC(21,21),FS(21,21),AL(9,21),
     3 NQ(21),ISAVE(21),LIS(20)
      COMMON K,L,LI,LJ,ORL,DEK,IC,FKL,FL,AL,EV,EVN,RSIZE,TAL,
     1RMOV,NUSE,IPS,SIZE,F1,NJLAB,FS,LAB,Q
      WRITE(6,1)
    1 FORMAT(14H ENTERED ALLOC)
      IX=1
      DO 100 I=1,LI
C READ IN EXISTING ALLOCATIONS AND FLOWS
      DO 101 IK=1,LI
      IP(IK)=IPS(IK)
      LAB(IK)=0
      Q(IK)=0.
      ISAVE(IK)=0
      DO 101 JK=1,LJ
  101 F(IK,JK)=FS(IK,JK)
      ALL=RMOV(K)
  203 AL(K,I)=AL(K,I)+ALL
      ORL(I)=ALL*FL(K,L)
```

```
      DO 102 J=1,LJ
      IF(I-J) 207,102,207
  207 IF(AL(L,J)-.001) 102,102,208
  208 DEK(J)=ORL(I)*AL(L,J)/RSIZE(L)
      IF(F(J,I)-.001) 209,209,204
  204 IF(DEK(J)-F(J,I)) 205,205,206
  205 CF=IC(J,I)
      FKL=FKL-DEK(J)*CF
      F(J,I)=F(J,I)-DEK(J)
      GO TO 102
  206 CF=IC(J,I)
      FKL=FKL-F(J,I)*CF
      F(I,J)=DEK(J)-F(J,I)
      CF=IC(I,J)
      FKL=FKL+(DEK(J)-F(J,I))*CF
      F(J,I)=0.
      GO TO 210
  209 F(I,J)=F(I,J)+DEK(J)
      CF=IC(I,J)
      FKL=FKL+DEK(J)*CF
C KILTER CHECK
  210 IF(F(I,J)-.0001) 102,102,999
  999 IF(IC(I,J)+IP(I)-IP(J)) 211,102,212
C OKIL- NEGATIVE CIJ
  211 LAB(J)=I
      ITERM=I
      Q(J)=99999.
      ISAVE(IX)=J
      IX=IX+1
      JC=J
      GO TO 213
C OKIL- POSITIVE CIJ AND FLOW
  212 LAB(I)=-J
      ITERM=J
      Q(I)=F(I,J)
      ISAVE(IX)=I
      IX =IX+1
      IR=I
C LABEL COLUMNS
  213 N=0
  214 N=N+1
      IR=ISAVE(N)
      DO 103 JC=1,LJ
      IF(AL(L,JC)-.0001)103,215,215
  215 IF(LAB(JC))103,216,103
C ROUTE PRICE
  216 IF(IC(IR,JC)+IP(IR)-IP(JC)) 217,217,103
  217 LAB(JC)=IR
      Q(JC)=Q(IR)
  218 ISAVE(IX)=JC
      IX=IX+1
      IF(JC-ITERM)103,225,103
  103 CONTINUE
      JC=IR
      DO 104 IR=1,LI
       IF(AL(K,IR)-.0001)104,219,219
  219 IF(LAB(IR))104,220,104
C ROUTE PRICE
  220 IF(IC(IR,JC)+IP(IR)-IP(JC)) 104,221,221
  221 IF(F(IR,JC)-.0001)104,104,222
  222 LAB(IR)=-JC
```

```
      Q(IR)=F(IR,JC)
      IF(Q(IR)-Q(JC))224,224,223
  223 Q(IR)=Q(JC)
  224 ISAVE(IX)=IR
      IX=IX+1
      IF((IR-ITERM)104,226,104
  104 CONTINUE
      IF(ISAVE(N+1))214,250,214
C ALTER FLOW
  225 NJ=JC
      GO TO 228
  226 NJ=IR
  228 DEL=Q(NJ)
  229 IF(LAB(NJ)) 231,230,232
  230 WRITE(6,21)NJ
   21 FORMAT(14H TRACING ERROR,I4)
      STOP
  231 NI=IABS(LAB(NJ))
      F(NJ,NI)=F(NJ,NI)-DEL
      CF=IC(NJ,NI)
      FKL=FKL-DEL*CF
      GO TO 233
  232 NI=LAB(NJ)
      F(NI,NJ)=F(NI,NJ)+DEL
      CF=IC(NI,NJ)
      FKL=FKL+DEL*CF
  233 NJ=NI
      IF(NJ-ITERM) 229,234,229
  250 DEKT=0.
      DO 7777 IH=1,LI
      DEKT =DEKT+DEK(IH)
 7777 CONTINUE
      IF(DEKT-.0001)7778,7778,2500
 2500 IDPR=999999
      IDNPR=-999999
  251 DO 107 IG=1,LI
      IF(AL(K,IG)-.0001) 107,252,252
  252 IF(LAB(IG))253,254,253
  253 DO 108 JD=1,LJ
      IF(AL(L,JD)-.0001) 108,108,255
  255 IF(LAB(JD)) 108,257,108
  257 IPRR=IC(IG,JD)+IP(IG)-IP(JD)
      IF(IPRR) 108,108,259
  259 IF(IPRR-IDPR) 270,108,108
  270 IDPR=IPRR
  108 CONTINUE
      GO TO 107
  254 DO 109 JD=1,LJ
      IF(AL(L,JD)-.0001) 109,109,256
  256 IF(LAB(JD)) 258,109,258
  258 IPRR=IC(IG,JD)+IP(IG)-IP(JD)
  273 IF(IPRR) 250,109,109
  260 IF(IPRR-IDNPR) 109,109,271
  271 IDNPR=IPRR
  109 CONTINUE
  107 CONTINUE
      IF(IDPR+IDNPR) 266,261,265
  265 IDPR=-IDNPR
      GO TO 266
  261 IF(IDPR-999999) 266,263,263
  263 WRITE(6,5) IDPR,IDNPR
```

```
    5 FORMAT(19H PRICING ERROR IDPR,I8,5HIDNPR,I8)
      STOP
  266 DO 110 IG=1,LI
      IF(AL(K,IG)-.0001) 267,267,268
  267 IF(AL(L,IG)-.0001) 110,110,268
  268 IF(LAB(IG)) 110,269,110
  269 IP(IG)=IP(IG)+IDPR
  110 CONTINUE
  234 DO 105 IT=1,LI
      Q(IT)=0.
      LAB(IT)=0
  105 ISAVE(IT)=0
      IX=1
      GO TO 210
  102 CONTINUE
 7778 EV(I)=EV(I)-(FKL-F1)/ALL*2.
      AL(K,I)=AL(K,I)-ALL
  298 FKL=F1
   10 FORMAT(27F4.0)
  100 CONTINUE
      WRITE(6,11)
   11 FORMAT(14H LEAVING ALLOC)
      RETURN
      END
$IBFTC SUBP3
      SUBROUTINE LABEL
      DIMENSION FL(10,10),SIZE(258),EV(21),EVN(21),F(21,21),
     1TAL(9,258),ORL(21),DEK(21),RSIZE(10),IP(21),RMOV(10),
     2IPS(21),LAB(21),Q(21),IC(21,21),FS(21,21),AL(9,21),
     3 NQ(21),ISAVE(21),LIS(20)
      COMMON K,L,LI,LJ,ORL,DEK,IC,FKL,FL,AL,EV,EVN,RSIZE,TAL,
     1RMOV,NUSE,IPS,SIZE,F1,NJLAB,FS,LAB,Q
C INITIALIZE FLOWS
      DO 9 I=1,LI
      DO 9 J=1,LJ
    9 FS(I,J)=0.
C     LABEL FLOW PATHS
   11 NULAB=0
      DO 12 I=1,LI
      IF(AL(K,I)-.0001) 12,12,13
   13 IF(LAB(I)) 20,19,20
   20 DO 18 J=1,LJ
      IF(AL(L,J)-.0001) 18,18,14
   14 IF(LAB(J)) 18,15,18
   15 IF(IC(I,J)+IPS(I)-IPS(J))16,16,18
   16 LAB(J)=I
      Q(J)=Q(I)
      IF(DEK(J)-.0001) 17,17,50
   17 NULAB = 1
   18 CONTINUE
      GO TO 12
   19 DO 21 J=1,LJ
      IF(AL(L,J)-.0001) 21,21,22
   22 IF(LAB(J)) 23,21,23
   23 IF(FS(I,J)-.0001)21,21,24
   24 LAB(I) = -J
      Q(I) = Q(J)
      IF(FS(I,J).LT.Q(I))Q(I)=FS(I,J)
      IF(DEK(I)-0.1) 25,25,49
   25 NULAB=1
   21 CONTINUE
```

```
   12 CONTINUE
      IF (NULAB) 60,60,11
   60 DEKT=0.
      DO 7777 IH=1,LI
      DEKT =DEKT+DEK(IH)
 7777 CONTINUE
      IF(DEKT-.0001)34,34,600
  600 IDPR=999999
      DO 71 I=1,LI
      IF(LAB(I))69,71,69
   69 DO 72 J=1,LJ
      IF(AL(I,J)-.0001)72,72,68
   68 IF(LAB(J))72,67,72
   67 IF(IC(I,J)+IPS(I)-IPS(J)-IDPR)96,72,72
   96 IF(IC(I,J)+IPS(I)-IPS(J))72,72,200
  200 IDPR=IC(I,J)+IPS(I)-IPS(J)
   72 CONTINUE
   71 CONTINUE
      IF(IDPR-999999)80,74,74
   80 DO 73 I=1,LI
      IF(AL(K,I)-.0001) 81,81,83
   81 IF(AL(L,I)-.0001) 73,73,83
   83 IF(LAB(I))73,82,73
   82 IPS(I)=IPS(I)+IDPR
   73 CONTINUE
   76 WRITE(6,77)(IPS(I),I=1,LI)
   77 FORMAT(11H NEW PRICES,9110)
      GO TO 11
   74 WRITE(6,75)K,L
   75 FORMAT(15H DPR EQUALS 999,2I4)
  100 WRITE (6,101) NJ
  101 FORMAT (1H ,4HLAB(,I2,6H).EQ.0)
  102 WRITE (6,103)
  103 FORMAT (10H RLAB IS -)
      WRITE(6,4)(ORL(I),DEK(I),LAB(I),I=1,LI)
    4 FORMAT(2F10.1,I10)
      WRITE(6,5)FS
    5 FORMAT(21F6.1)
   10 STOP
C
C     INCREMENT FLOW
   49 NJ=I
      NI=J
      J=NJ
      I=NI
      GO TO 51
   50 NI=I
      NJ = J
   51 IF(DEK(NJ).LT.Q(NJ)) Q(NJ)=DEK(NJ)
      DEL = Q(NJ)
      DEK(NJ) = DEK(NJ)-DEL
   52 IF(LAB(NJ)) 53,100,55
   53 FS(NJ,NI)=FS(NJ,NI)-DEL
      CF=IC(NJ,NI)
      FKL=FKL-DEL*CF
      Q(NJ) = Q(NJ)-DEL
      IF(LAB(NI)-999) 54,56,54
   54 NIS=NI
      NJ  = NI
      NI = IABS(LAB(NIS))
      GO TO 52
```

```
55 FS(NI,NJ)=FS(NI,NJ)+DEL
   CF=IC(NI,NJ)
   FKL=FKL+DEL*CF
   Q(NJ) = Q(NJ)-DEL
   IF(LAB(NI)-999) 54,56,54
56 ORL(NI) = ORL(NI)-DEL
   Q(NI) = Q(NI) - DEL
   IF(ORL(NI).LT.0.1) ORL(NI)=0.
   WRITE (6,57) FKL
57 FORMAT (4H FKL,E20.7)
30 RLAB=0.
   DO 31 I=1,LI
   IF(ORL(I)-.0001) 33,33,32
32 RLAB=1.
   GO TO 31
33 Q(I) =0.
   LAB(I)=0
   ORL(I)=0.
31 CONTINUE
   IF(RLAB) 102,34,11
34 WRITE (6,3)FS
 3 FORMAT(27F4.0)
   RETURN
```

A6. DUAL2

This program is a modification of FLOCOST designed to calculate, for each origin district, the intra-district flow costs and their contribution to the assumed flow costs.

In addition to the FLOCOST data types, it requires a list of locations by district and the number of locations per district. This additional data must be in the same order as in DUAL1.

```
3291,GRECCD,T200,CM70000,P10.
RUN(S)
LGO.
7
C
C                                DUAL2
C
C
C1   THIS PROGRAM CALCULATES THE INTRA-DISTRICT FLOW COSTS (ORIGIN
C    DISTRICT ONLY) AND THEIR CONTRIBUTION TO THE FLOW COST EVALUATORS
C2   DIMENSIONS HAVE BEEN SET FOR 21 DISTRICTS WITH A MAXIMUM OF 20 LOCATIONS
C     IN EACH DISTRICT
       PROGRAM DUAL2 (INPUT,OUTPUT,PUNCH,TAPE5=INPUT,
      1TAPE6=OUTPUT,TAPE7=PUNCH)
$ID    3291*10*50*100*GRECCD* DUAL2
$EXECUTE         IBJOB
$IBJOB           NOGO
$IBFTC MAIN
       DIMENSION FL(10,10),SIZE(20),EV(8,20),EVN(8,20),F(20,20),
      1AL(9,20),DRL(20),DEK(20),RSIZE(10),IP(20),LIS(20),
      2RMOV(10),IPS(20),LAB(20),Q(20),IC(20,20),NQ(21),
      3FS(20,20),ISAVE(20)
       COMMON K,L,LI,LJ,DRL,DEK,IC,IP,F,LAB,J,FK,FL,AL,EV,EVN,RSIZE,
      1RMOV,BMOV,NUSE,IPS,SIZE,FI,NULAB,FS
C VACANT USE LAST
    1 FORMAT(10F8.2)
    2 FORMAT (I5,F5.0, 9(3X,F3.0))
    3 FORMAT(10F8.2)
    4 FORMAT(20I4)
    5 FORMAT(2I4)
    6 FORMAT(I4,21I3)
    7 FORMAT(E20.7)
    8 FORMAT(1X,1P7E11.4)
   10 FORMAT(1X,5E12.4)
      NP=NUSE+1
C INPUT
      READ(5,1) FL,RSIZE,RMOV
      READ(5,5)NR,NUSE
C  NUSE DENOTES THE NUMBER OF USES
C  NR DENOTES THE NUMBER OF DISTRICTS
      READ(5,6)NQ
      TOTCO=0.
C  EVALUATORS FOR LAST USE (PJRDJE) ARE NOT CALCULATED
      NM=NUSE-1
      DO 501 II=1,NR
      LI=NQ(II)
      LJ=LI
      DO 500 I=1,LI
  500 READ(5,2)LIS(I),SIZE(I),(AL(K,I),K=1,NUSE)
      DO 502 III=1,LI
      READ(5,4)(IC(III,IJI),IJI=1,LI)
  502 CONTINUE
      WRITE(6,4)((IC(I,J),J=1,LI),I=1,LI)
C K DENOTES ORIGIN USE
C L DENOTES DESTINATION USE
      DO 100 K=1,NUSE
      FK=0.
      DO 900 IQ=1,LI
      EV(K,IQ)=0.
  900 EVN(K,IQ)=0.
      DO 101 L=1,NUSE
```

```
      FKL=0.
      IF(K-L) 210,101,210
  210 IF(FL(K,L)) 211,101,211
C CALCULATE TRIP ORIGINS AND DESTINATIONS
  211 SUML=0.
      IF(K-9) 212,510,212
C  ACCOUNT FOR PURDUE TRIPS FROM ONE ORIGIN ONLY
  510 IF(II-6)100,213,100
  212 DO 102 I=1,LI
      ORL(I)=FL(K,L)*AL(K,I)
  102 SUML=SUML+ORL(I)
      IF(L-9) 214,511,214
C  ACCOUNT FOR PURDUE TRIPS FROM ONE DESTINATION ONLY
  511 IF(II-6)101,298,101
  298 DO 108 J=1,LJ
  108 DEK(J)=0.
      DEK(7)=SUML
      GO TO 221
  213 DO 109 I=1,LI
  109 ORL(I)=0.
      ORL(7)=FL(K,L)*AL(K,7)
  214 DO 103 J=1,LJ
  103 DEK(J)=SUML*AL(L,J)/RSIZE(L)
C CONVERT NETWORK TO TRANSPO AND LABEL ORIGINS
  221 DO 110 I=1,LI
      LAB(I)=0
      Q(I)=0.
      IF(ORL(I)-.0001)110,252,252
  252 IF(ORL(I)-DEK(I)-0.1) 253,253,254
  253 DEK(I)=DEK(I)-ORL(I)
      ORL(I)=0.
      IF(DEK(I)-.001) 255,110,110
  254 ORL(I)=ORL(I)-DEK(I)
C LABEL ORIGINS
      LAB(I)=999
      Q(I)=ORL(I)
  255 DEK(I)=0.
  110 CONTINUE
C     INITIAL PRICE VECTOR
  222 DO 104 J=1,LJ
      IPS(J)=0
      IF(DEK(J)-.001) 104,104,215
  215 IPS(J)=999999
      DO 105 I=1,LI
      IF(ORL(I)-.001) 105,105,216
  216 IF(IC(I,J)-IPS(J))217,105,217
  217 IPS(J)=IC(I,J)
  105 CONTINUE
  104 CONTINUE
      CALL LABEL
      F1=FKL
C  FOR PURDUE(FIXED LOCATIONS) DELETE EVALUATORS
      IF(K-9)218,512,512
  218 CALL REA
  220 CALL ALLOC
  223 WRITE(6,21)(EV(K,I),I=1,LI)
      WRITE(6,21)(EVN(K,I),I=1,LI)
   21 FORMAT(17H EVALUATORS +AND-/1X,10E13.5)
  512 FK=FK+F1
  101 CONTINUE
      PUNCH 9,(LIS(I),(EV(K,I),K=1,NM),I=1,LI)
```

```
      PUNCH 9,(LIS(I),(EVN(K,I),K=1,NM),I=1,LI)
    9 FORMAT(I4,5E12.4)
  100 TOTCO=TOTCO+FK
      WRITE(6,22) FKL,FK
   22 FORMAT(8H FKL EQ ,E15.5,6HFK EQ ,E15.5)
      WRITE(6,23) TOTCO
   23 FORMAT(14H TOTCO EQUALS ,E20.7)
  501 CONTINUE
      WRITE(6,23)TOTCO
      STOP
      END
$IBFTC SUBP1
      SUBROUTINE REA
      DIMENSION FL(10,10),SIZE(20),EV(8,20),EVN(8,20),F(20,20),
     1AL(9,20),ORL(20),DEK(20),RSIZE(10),IP(20),LIS(20),
     2RMOV(10),IPS(20),LAB(20),Q(20),IC(20,20),NQ(21),
     3FS(20,20),ISAVE(20)
      COMMON K,L,LI,LJ,ORL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,EVN,RSIZE,
     1RMOV,BMOV,NUSE,IPS,SIZE,FI,NULAB,FS
      WRITE(6,1)
    1 FORMAT(12H ENTERED REA)
C FORMS REALLOCATION MATRIX USING NODE PRICES FOR FLOW COSTS
      DO 100 I=1,LI
      IF(AL(K,I)-.0001) 100,100,200
  200 DO 101 J=1,LJ
      IF(AL(L,J)-.0001) 101,101,201
  201 PRJ=IPS(J)
      EVN(K,I)=EVN(K,I)-AL(L,J)*FL(K,L)*PRJ/RSIZE(L)*2.
  101 CONTINUE
      PRI=IPS(I)
C     EVN(K,I)=EVN(K,I)+PRI*FL(K,L)*2.
  100 CONTINUE
      WRITE(6,2)K,L,(EVN(K,I),I=1,LI)
    2 FORMAT(18H FINISHED REA K EQ,I2,2X,4HL EQ,I2/(9E13.5))
      RETURN
      END
$IBFTC SUBP2
      SUBROUTINE ALLOC
      DIMENSION FL(10,10),SIZE(20),EV(8,20),EVN(8,20),F(20,20),
     1AL(9,20),ORL(20),DEK(20),RSIZE(10),IP(20),LIS(20),
     2RMOV(10),IPS(20),LAB(20),Q(20),IC(20,20),NQ(21),
     3FS(20,20),ISAVE(20)
      COMMON K,L,LI,LJ,ORL,DEK,IC,IP,F,LAB,Q,FKL,FL,AL,EV,EVN,RSIZE,
     1RMOV,BMOV,NUSE,IPS,SIZE,FI,NULAB,FS
      WRITE(6,1)
    1 FORMAT(14H ENTERED ALLOC).
      IX=1
      DO 100 I=1,LI
C READ IN EXISTING ALLOCATIONS AND FLOWS
      DO 101 IK=1,LI
      IP(IK)=IPS(IK)
      LAB(IK)=0
      Q(IK)=0.
      ISAVE(IK)=0
      DO 101 JK=1,LJ
  101 F(IK,JK)=FS(IK,JK)
      ALL=RMOV(K)
      IF(ALL-SIZE(I)+AL(K,I)) 203,203,202
  202 ALL=SIZE(I)-AL(K,I)
      IF(ALL-.0001) 299,299,203
  299 EV(I)=EVN(I)
```

```
      GO TO 298
  203 AL(K,I)=AL(K,I)+ALL
      ORL(I)=ALL*FL(K,L)
      DO 102 J=1,LJ
      IF(I-J) 207,102,207
  207 IF(AL(L,J)-.001) 102,102,208
  208 DEK(J)=ORL(I)*AL(L,J)/RSIZE(L)
      IF(F(J,I)-.001) 209,209,204
  204 IF(DEK(J)-F(J,I)) 205,205,206
  205 CF=IC(J,I)
      FKL=FKL-DEK(J)*CF
      F(J,I)=F(J,I)-DEK(J)
      GO TO 102
  206 CF=IC(J,I)
      FKL=FKL-F(J,I)*CF
      F(I,J)=DEK(J)-F(J,I)
      CF=IC(I,J)
      FKL=FKL+(DEK(J)-F(J,I))*CF
      F(J,I)=0.
      GO TO 210
  209 F(I,J)=F(I,J)+DEK(J)
      CF=IC(I,J)
      FKL=FKL+DEK(J)*CF
C KILTER CHECK
  210 IF(F(I,J)-.0001) 102,102,999
  999 IF(IC(I,J)+IP(I)-IP(J)) 211,102,212
C OKIL- NEGATIVE CIJ
  211 LAB(J)=I
      ITERM=I
      Q(J)=99999.
      ISAVE(IX)=J
      IX=IX+1
      JC=J
      GO TO 213
C OKIL- POSITIVE CIJ AND FLOW
  212 LAB(I)=-J
      ITERM=J
      Q(I)=F(I,J)
      ISAVE(IX)=I
      IX =IX+1
      IR=I
C LABEL COLUMNS
  213 N=0
  214 N=N+1
      IR=ISAVE(N)
      DO 103 JC=1,LJ
      IF(AL(L,JC)-.0001)103,215,215
  215 IF(LAB(JC))103,216,103
C ROUTE PRICE
  216 IF(IC(IR,JC)+IP(IR)-IP(JC)) 217,217,103
  217 LAB(JC)=IR
      Q(JC)=Q(IR)
  218 ISAVE(IX)=JC
      IX=IX+1
      IF(JC-ITERM)103,225,103
  103 CONTINUE
      JC=IR
      DO 104 IR=1,LI
       IF(AL(K,IR)-.0001)104,219,219
  219 IF(LAB(IR))104,220,104
C ROUTE PRICE
```

```
  220 IF(IC(IR,JC)+IP(IR)-IP(JC)) 104,221,221
  221 IF(F(IR,JC)-.0001)104,104,222
  222 LAB(IR)=-JC
      Q(IR)=F(IR,JC)
      IF(Q(IR)-Q(JC))224,224,223
  223 Q(IR)=Q(JC)
  224 ISAVE(IX)=IR
      IX=IX+1
      IF(IR-ITERM)104,226,104
  104 CONTINUE
      IF(ISAVE(N+1))214,250,214
C ALTER FLOW
  225 NJ=JC
      GO TO 228
  226 NJ=IR
  228 DEL=Q(NJ)
  229 IF(LAB(NJ)) 231,230,232
  230 WRITE(6,21)NJ
   21 FORMAT(14H TRACING ERROR,I4)
      STOP
  231 NI=IABS(LAB(NJ))
      F(NJ,NI)=F(NJ,NI)-DEL
      CF=IC(NJ,NI)
      FKL=FKL-DEL*CF
      GO TO 233
  232 NI=LAB(NJ)
      F(NI,NJ)=F(NI,NJ)+DEL
      CF=IC(NI,NJ)
      FKL=FKL+DEL*CF
  233 NJ=NI
      IF(NJ-ITERM) 229,234,229
  250 DEKT=0.
      DO 7777 IH=1,LI
      DEKT =DEKT+DEK(IH)
 7777 CONTINUE
      IF(DEKT-.0001)7778,7778,2500
 2500 IDPR=999999
      IDNPR=-999999
  251 DO 107 IG=1,LI
      IF(AL(K,IG)-.0001) 107,252,252
  252 IF(LAB(IG))253,254,253
  253 DO 108 JD=1,LJ
      IF(AL(L,JD)-.0001) 108,108,255
  255 IF(LAB(JD)) 108,257,108
  257 IPRR=IC(IG,JD)+IP(IG)-IP(JD)
      IF(IPRR) 108,108,259
  259 IF(IPRR-IDPR) 270,108,108
  270 IDPR=IPRR
  108 CONTINUE
      GO TO 107
  254 DO 109 JD=1,LJ
      IF(AL(L,JD)-.0001) 109,109,256
  256 IF(LAB(JD)) 258,109,258
  258 IPRR=IC(IG,JD)+IP(IG)-IP(JD)
  273 IF(IPRR) 260,109,109
  260 IF(IPRR-IDNPR) 109,109,271
  271 IDNPR=IPRR
  109 CONTINUE
  107 CONTINUE
      IF(IDPR+IDNPR) 266,261,265
  265 IDPR=-IDNPR
```

```
      GO TO 266
  261 IF(IDPR-999999) 266,263,263
  263 WRITE(6,5) IDPR,IDNPR
    5 FORMAT(19H PRICING ERROR IDPR,I8,5HIDNPR,I8)
      STOP
  266 DO 110 IG=1,LI
      IF(AL(K,IG)-.0001) 267,267,268
  267 IF(AL(L,IG)-.0001) 110,110,268
  268 IF(LAB(IG)) 110,269,110
  269 IP(IG)=IP(IG)+IDPR
  110 CONTINUE
  234 DO 105 IT=1,LI
      Q(IT)=0.
      LAB(IT)=0
  105 ISAVE(IT)=0
      IX=1
      GO TO 210
  102 CONTINUE
 7778 EV(K,I)=EV(K,I)-(FKL-FI)/ALL*2.
      AL(K,I)=AL(K,I)-ALL
  298 FKL=FI
      WRITE(6,10)((F(IB,J),J=1,9),IB=1,9)
   10 FORMAT(27F4.0)
  100 CONTINUE
      WRITE(6,11)
   11 FORMAT(14H LEAVING ALLOC)
      RETURN
      END
$IBFTC SUBP3
      SUBROUTINE LABEL
      DIMENSION FL(10,10),SIZE(20),EV(8,20),EVN(8,20),F(20,20),
     1AL(9,20),ORL(20),DEK(20),RSIZE(10),IP(20),LIS(20),
     2RMOV(10),IPS(20),LAB(20),Q(20),IC(20,20),NU(21),
     3FS(20,20),ISAVE(20)
      COMMON K,L,LI,LJ,ORL,DEK,IC,IP,F,LAB,J,FKL,FL,AL,EV,EVN,RSIZE,
     1RMOV,BMOV,NUSE,IPS,SIZE,FI,NULAB,FS
C INITIALIZE FLOWS
      DO 9 I=1,LI
      DO 9 J=1,LJ
    9 FS(I,J)=0.
C     LABEL FLOW PATHS
   11 NULAB=0
      DO 12 I=1,LI
      IF(AL(K,I)-.0001) 12,12,13
   13 IF(LAB(I)) 20,19,20
   20 DO 18 J=1,LJ
      IF(AL(L,J)-.0001) 18,18,14
   14 IF(LAB(J)) 18,15,18
   15 IF(IC(I,J)+IPS(I)-IPS(J))16,16,18
   16 LAB(J)=I
      Q(J)=Q(I)
      IF(DEK(J)-.0001) 17,17,50
   17 NULAB = 1
   18 CONTINUE
      GO TO 12
   19 DO 21 J=1,LJ
      IF(AL(L,J)-.0001) 21,21,22
   22 IF(LAB(J)) 23,21,23
   23 IF(FS(I,J)-.0001)21,21,24
   24 LAB(I) = -J
      Q(I) = Q(J)
```

```
      IF(FS(I,J).LT.Q(I))Q(I)=FS(I,J)
      IF(DEK(I)-0.1) 25,25,49
   25 NULAB=1
   21 CONTINUE
   12 CONTINUE
      IF (NULAB) 60,60,11
   60 DEKT=0.
      DO 7777 IH=1,LI
      DEKT =DEKT+DEK(IH)
 7777 CONTINUE
      IF(DEKT-.0001)34,34,600
  600 IDPR=999999
      DO 71 I=1,LI
      IF(LAB(I))59,71,69
   69 DO 72 J=1,LJ
      IF(AL(I,J)-.0001)72,72,68
   68 IF(LAB(J))72,67,72
   67 IF(IC(I,J)+IPS(I)-IPS(J)-IDPR)96,72,72
   96 IF(IC(I,J)+IPS(I)-IPS(J))72,72,200
  200 IDPR=IC(I,J)+IPS(I)-IPS(J)
   72 CONTINUE
   71 CONTINUE
      IF(IDPR-999999)80,74,74
   80 DO 73 I=1,LI
      IF(AL(K,I)-.0001) 81,81,83
   81 IF(AL(L,I)-.0001) 73,73,83
   83 IF(LAB(I))73,82,73
   82 IPS(I)=IPS(I)+IDPR
   73 CONTINUE
   76 WRITE(6,77)(IPS(I),I=1,LI)
   77 FORMAT(11H NEW PRICES,9I10)
      GO TO 11
   74 WRITE(6,75)K,L
   75 FORMAT(15H DPR EQUALS 999,2I4)
  100 WRITE (6,101) NJ
  101 FORMAT (1H ,44LAB(,I2,6H).EQ.0)
  102 WRITE (6,103)
  103 FORMAT (10H RLAB IS -)
      WRITE(6,4)(DRL(I),DEK(I),LAB(I),I=1,LI)
    4 FORMAT(2F10.1,I10)
      WRITE(6,5)FS
    5 FORMAT(9F8.1)
      WRITE(6,2)(LAB(I),I=1,LI)
   10 STOP
C
C     INCREMENT FLOW
   49 NJ=I
      NI=J
      J=NJ
      I=NI
      GO TO 51
   50 NI=I
      NJ = J
   51 IF(DEK(NJ).LT.Q(NJ)) Q(NJ)=DEK(NJ)
      DEL = Q(NJ)
      DEK(NJ) = DEK(NJ)-DEL
   52 IF(LAB(NJ)) 53,100,55
   53 FS(NJ,NI)=FS(NJ,NI)-DEL
      CF=IC(NJ,NI)
      FKL=FKL-DEL*CF
      Q(NJ) = Q(NJ)-DEL
```

```
      IF(LAB(NI)-999) 54,56,54
   54 NIS=NI
      NJ  = NI
      NI  = IABS(LAB(NIS))
      GO TO 52
   55 FS(NI,NJ)=FS(NI,NJ)+DEL
      CF=IC(NI,NJ)
      FKL=FKL+DEL*CF
      Q(NJ) = Q(NJ)-DEL
      IF(LAB(NI)-999) 54,56,54
   56 ORL(NI) = ORL(NI)-DEL
      Q(NI) = Q(NI) - DEL
      IF(ORL(NI).LT.0.1) ORL(NI)=0.
      WRITE (6,57) FKL
   57 FORMAT (4H FKL,F10.1)
   30 RLAB=0.
      DO 31 I=1,LI
      IF(ORL(I)-.0001) 33,33,32
   32 RLAB=1.
      GO TO 31
   33 Q(I) =0.
      LAB(I)=0
      ORL(I)=0.
   31 CONTINUE
      IF(RLAB) 102,34,11
   34 WRITE(6,3)FS
    3 FORMAT(27F4.0)
    2 FORMAT (9I5)
      RETURN
      END
7
```

A7. REALOC LAFAYETTE USES

This program is a simplified version of REALOC, since there are no multi-use activities considered in the Lafayette application. The output allocation matrices are arranged to renumber the Lafayette locations to coincide with the numbering shown in Figure C1, reinserting the flood plain and cemetery locations which were deleted in the preceding program data.

As in DUAL1 and DUAI2, a list of locations for each district (LISI) is required in addition to the REALOC data types. This must be in the same order as in the preceding programs. The output flow evaluator components and costs from DUAL1 and DUAL2 are combined prior to the construction of the initial evaluator matrix.

```
3291,GRECCO,T400,CM125000,P10.
RUN(S)
LGO(LC,40000)
7
      PROGRAM REALOC(INPUT,OUTPUT,PUNCH,TAPE5=INPUT,
     1TAPE6=OUTPUT,TAPE7=PUNCH)
C
C                              REALOC LAFAYETTE USES
C
C
C  REALLOCATES ACTIVITIES WITHIN INTERCHANGE LIMITS
C  DIMENSIONS ARE SET FOR 9 USES AND 258 LOCATIONS
      DIMENSION AL(10,258),ALI(10,258),ALM(9,258),ALP(9,258),
     1CAP(9,258),E(9,258),EV(9,258),EVN(9,258),TEV(9,21),TEVN(9,21),
     2EX(9,258),EXN(9,258),ORL(10),DEK(258),NLAB(10),LAB(258),
     3QN(10),Q(258),SIZE(258),IP(258),RMOV(10),TX(9,258),IPN(10),
     4RINC(9,258),RSIZE(10),LIS(30),LISI(20),NQ(21)
C  INITIAL VALUES
      LI=258
C  LI DENOTES THE NUMBER OF LOCATIONS
      NUSE=9
C  NUSE DENOTES THE NUMBER OF USES
      LJ=LI
      NP=NUSE+1
    1 FORMAT(5X,F5.3,20F3.0)
    2 FORMAT(10F8.2)
    3 FORMAT(9H1LOCATION,9X,32HINITIAL ALLOCATION OF USE NUMBER///55
     1H NO  SIZE     1    2    3    4    5    6    7    8    9//)
    4 FORMAT(4X,18F4.0)
    5 FORMAT(1X,1P7E11.4)
    6 FORMAT(E20.7)
    7 FORMAT(9H1LOCATION,12X,26HREALLOCATION OF USE NUMBER////55
     1H NO  SIZE     1    2    3    4    5    6    7    8    9//)
    8 FORMAT(I4,F6.3,1X,9F5.0)
    9 FORMAT(1H1)
   10 FORMAT(1X,1P7E11.4)
   11 FORMAT(10H IOPR =999)
   12 FORMAT(10F5.1)
   17 FORMAT(I4,3X,24HFLOOD PLAIN AND OR RIVER)
   18 FORMAT(I4,3X,9HCEMETERY)
   19 FORMAT(20I4)
   20 FORMAT(21I3)
   21 FORMAT(I4,9F9.0)
   22 FORMAT(1X,9F8.0)
C  INPUT
      READ(5,1)(SIZE(I),(ALI(K,I),AL(K,I),K=1,NP),I=1,LI)
C  SIZE(I) DENOTES THE AREA OF LOCATION I IN ACRES
C  ALI AND AL DENOTE THE EXISTING AND ALLOCATED USES, RESPECTIVELY
      READ(5,2)RMOV
C  RMOV DENOTES THE MAXIMUM INTERCHANGE LIMITS
      READ(5,4)((EX(K,I),EXN(K,I),K=1,NUSE),I=1,LI)
C  EX AND EXN DENOTE THE LOCATION RETURNS FOR CHANGE OF USE
C    AND REALLOCATION OF EXISTING USES RESPECTIVELY
      READ(5,5)((RINC(K,I),I=1,LI),K=1,NUSE)
C  RINC DENOTES THE OUTPUT OF INCOMP - UNIT INCOMPATIBILITY COST
      READ(5,19)LIS
C  LIS IS A LIST OF FLOOD PLAIN LOCATIONS NOT CONSIDERED IN THE COMPUTATIONS
      READ(5,6)TOTCO
C  TOTCO IS THE SUM OF FLOW COSTS FROM DUAL1 AND DUAL2
      DO 39 K=1,NUSE
      READ(5,22)(TEV(K,I),I=1,21)
```

```
   39 READ(5,22)(TEVN(K,I),I=1,21)
C  TEV AND TEVN ARE THE UNIT FLOW COSTS FROM DUAL1
C  REARRANGE DUAL 2 OUTPUT IN PROPER SEQUENCE
      READ(5,20)NQ
C  NQ DENOTES THE NUMBER OF LOCATIONS IN EACH DISTRICT
      NM=NUSE-1
      DO 40 II=1,21
      NR=NQ(II)
      READ(5,19)LISI
C  LISI DENOTES A LIST OF LOCATIONS IN THE GIVEN DISTRICT
      DO 40 JI=1,NR
      I=LISI(JI)
      READ(5,21)(EV(K,I),K=1,NM)
      DO 41 K=1,NM
   41 EV(K,I)=EV(K,I)+TEV(K,II)
      READ(5,21)(EVN(K,I),K=1,NM)
C  EV AND EVN DENOTE THE UNIT FLOW COSTS FROM DUAL2
      DO 42 K=1,NM
      EVN(K,I)=EVN(K,I)+TEVN(K,II)
      IF(EVN(K,I).LT.EV(K,I))EVN(K,I)=EV(K,I)
   42 CONTINUE
   40 CONTINUE
C  CONVERT INCOMPATIBILITY AND RETURN TO ANNUAL CAPITAL
C  AND INTEREST COSTS
      DO 50 K=1,NUSE
      DO 51 I=1,LI
      EV(K,I)=-EV(K,I)
      EVN(K,I)=-EVN(K,I)
      RINC(K,I)=RINC(K,I)*.07823
      IF(EXN(K,I))61,60,61
   60 EXN(K,I)=EX(K,I)
   61 EXN(K,I)=EXN(K,I)*.07823
      EX(K,I)=EX(K,I)*.07823
      IF(AL(K,I)-ALI(K,I))62,53,63
C  COMPUTE THE TOTAL COST OF THE CURRENT (INPUT) SOLUTION
   62 XTOT=AL(K,I)*(EXN(K,I)-EX(K,I))
      GO TO 51
   63 XTOT=ALI(K,I)*(EXN(K,I)-EX(K,I))
   51 TOTCO=TOTCO+AL(K,I)*(RINC(K,I)-EX(K,I))-XTOT
   50 CONTINUE
C  LIST THE CURRENT ALLOCATION
      WRITE(6,3)
      IM=1
      NIM=1
      ICO=0
      DO 52  I=1,289
      ICO=ICO+1
      IF(ICO-45)70,70,71
   71 WRITE(6,9)
      WRITE(6,3)
      ICO=0
   70 IF(I-LIS(NIM))72,73,72
   73 WRITE(6,17)I
      NIM =NIM+1
      GO TO 52
   72 IF(I-97)74,75,74
   75 WRITE(6,18)I
      GO TO 52
   74 WRITE(6,8)I,SIZE(IM),(AL(K,IM),K=1,NUSE)
      IM =IM+1
   52 CONTINUE
```

```
      WRITE(6,9)
      WRITE(6,61)TOTCO
C  SET UP AS TRANSPORTATION PROBLEM
      DO 100 I=1,LI
  100 DEK(I)=AL(NP,I)
      DO 101 K=1,NUSE
      ORL(K)=0.
      DO 102 I=1,LI
      ALP(K,I)=0.
      DEC=RMOV(K)*.5
      IF(AL(K,I)-DEC)200,201,201
  200 DEC=AL(K,I)
  201 ALM(K,I)=AL(K,I)-DEC
      ORL(K)=ORL(K)+DEC
      DEK(I)=DEK(I)+DEC
      TX(K,I)=AL(K,I)+RMOV(K)
      IF(TX(K,I)-SIZE(I))102,102,203
  203 TX(K,I)=SIZE(I)
  102 CONTINUE
  101 CONTINUE
      ORL(NP)=0.
      ICH=0
C  BUILD EVALUATOR MATRIX
  212 DO 103 L=1,NUSE
      DO 103 J=1,LJ
      ALN=ALP(L,J)+ALM(L,J)
      E(L,J)=RINC(L,J)
      IF(ALN-ALI(L,J))204,205,205
  204 E(L,J)=E(L,J)-EXN(L,J)
      CAP(L,J)=ALI(L,J)-ALN
      IF(CAP(L,J)+ALN-TX(L,J))207,207,206
  205 E(L,J)=E(L,J)-EX(L,J)
  206 CAP(L,J)=TX(L,J)-ALN
  207 IF(AL(L,J)-ALN)209,209,208
  209 E(L,J)=E(L,J)+EV(L,J)
      GO TO 103
  208 E(L,J)=E(L,J)+EVN(L,J)
  210 IF(AL(L,J)-ALN-CAP(L,J))211,103,103
  211 CAP(L,J)=AL(L,J)-ALN
  103 CONTINUE
      IF(ICH.EQ.1) GO TO 219
C  INITIAL PRICE AND LABEL VECTORS
      NLAB(NP)=0
      DO 105 K=1,NUSE
      IPN(K)=0
      IF(ORL(K)-.0001)216,216,215
  215 NLAB(K)=999
      QN(K)=ORL(K)
      GO TO 105
  216 NLAB(K)=0
      QN(K)=0.
  105 CONTINUE
      DO 106 J=1,LJ
      LAB(J)=0
      Q(J)=0.
      IP(J)=0
      IF(DEK(J)-.0001)106,106,217
  217 IP(J)=999999
      DO 107 K=1,NUSE
      IE=E(K,J)*10.
      IF(IE-IP(J))218,107,107
```

```
  218 IP(J)=IE
  107 CONTINUE
  106 CONTINUE
C  LABEL FLOW PATHS
  219 NULAB=0
      DO 108 K=1,NUSE
      IF(NLAB(K))220,230,220
  220 DO 109 J=1,LJ
      IF(LAB(J))109,221,109
  221 IE=E(K,J)*10.
      IF(IE+IPN(K)-IP(J))222,222,109
  222 Q(J)=QN(K)
      IF(CAP(K,J).LT.Q(J))Q(J)=CAP(K,J)
      IF(Q(J)-.0001)109,109,223
  223 IF(DEK(J)-.0001)224,224,234
  224 NULAB=1
      LAB(J)=K
  109 CONTINUE
      GO TO 108
  230 DO 110 J=1,LJ
      IF(LAB(J))231,110,231
  231 IF(ALP(K,J)-.0001)110,110,232
  232 IE=E(K,J)*10.
      IF(IE+IPN(K)-IP(J))110,233,233
  233 NLAB(K)=-J
      QN(K)=Q(J)
      IF(ALP(K,J).LT.QN(K))QN(K)=ALP(K,J)
      NULAB=1
  110 CONTINUE
  108 CONTINUE
      IF(NULAB)250,250,219
C  INCREMENT ALLOCATION
  234 NI=K
      NJ=J
      ICH=0
  235 IF(DEK(NJ).LT.Q(NJ))Q(NJ)=DEK(NJ)
      DEL=Q(NJ)
      DEK(NJ)=DEK(NJ)-DEL
  236 ALP(NI,NJ)=ALP(NI,NJ)+DEL
      CAP(NI,NJ)=CAP(NI,NJ)-DEL
      Q(NJ)=Q(NJ)-DEL
      IF(NLAB(NI)-999)237,238,237
  237 NIS=NI
      NJ=NI
      NI=-NLAB(NIS)
      ALP(NJ,NI)=ALP(NJ,NI)-DEL
      CAP(NJ,NI)=CAP(NJ,NI)+DEL
      QN(NJ)=QN(NJ)-DEL
      NIS=NI
      NJ=NI
      NI=LAB(NIS)
      GO TO 236
  238 ORL(NI)=ORL(NI)-DEL
      QN(NI)=QN(NI)-DEL
  242 ILAB=0
      DO 111 K=1,NUSE
      IF(ORL(K)-.0001)244,244,243
  243 ILAB=1
      QN(K)=ORL(K)
      NLAB(K)=999
      GO TO 111
```

```
  244 QN(K)=0.
      NLAB(K)=0
      ORL(K)=0.
  111 CONTINUE
      DO 112 J=1,LJ
      Q(J)=0.
  112 LAB(J)=0
      IF(ILAB)245,245,219
  245 DO 113 K=1,NJSE
      RSIZE(K)=0.
      RMOV(K)=RMOV(K)*.5
      DO 113 J=1,LJ
      AL(K,J)=ALM(K,J)+ALP(K,J)
  113 RSIZE(K)=RSIZE(K)+AL(K,J)
      DO 114 I=1,LI
  114 AL (NP,I)=DEK(I)
C  LIST THE NEW ALLOCATION
      WRITE(6,7)
      IM=1
      NIM=1
      ICO=0
      DO 115 I=1,289
      ICO=ICO+1
      IF(ICO-45)274,274,246
  246 WRITE(6,9)
      WRITE(6,7)
      ICO=0
  274 IF(I-LIS(NIM))270,271,270
  271 WRITE(6,17)I
      NIM =NIM+1
      GO TO 115
  270 IF(I-97) 272,273,272
  273 WRITE(6,18)I
      GO TO 115
  272 WRITE(6,8)I,SIZE(IM),(ALIK,IM),K=1,NJSE)
      IM =IM+1
  115 CONTINUE
      WRITE(6,9)
      WRITE(6,12)RSIZE
      PUNCH 1,(SIZE(I), (ALI(K,I),AL(K,I),K=1,NP),I=1,LI)
      PUNCH 2,RSIZE
      STOP
  250 IF(ICH-1)2500,251,2500
 2500 ICH=1
      GO TO 212
C  REVISE PRICES
  251 IDPR=999999
      ICH=0
      DO 116 K=1,NJSE
      IF(NLAB(K))252,253,252
  252 DO 117 J=1,LJ
      IF(LAB(J))117,254,117
  254 IE=E(K,J)*10.
      IF(IE+IPN(K)-IP(J)-IDPR)255,117,117
  255 IF(IE+IPN(K)-IP(J))117,117,262
  262 IDPR=IE+IPN(K)-IP(J)
  117 CONTINUE
      GO TO 116
  253 DO 118 J=1,LJ
      IF(LAB(J))256,118,256
  256 IE=E(K,J)*10.
```

```
      IF(IE+IPN(K)-IP(J)+IDPR)118,118,257
  257 IF(IE+IPN(K)-IP(J))263,118,118
  263 IDPR=IP(J)-IPN(K)-IE
  118 CONTINUE
  116 CONTINUE
      IF(IDPR-999999)258,260,260
  258 DO 119 J=1,LJ
      IF(LAB(J))119,259,119
  259 IP(J)=IP(J)+IDPR
  119 CONTINUE
      DO 120 K=1,NUSE
      IF(NLAB(K))120,261,120
  261 IPN(K)=IPN(K)+IDPR
  120 CONTINUE
      GO TO 219
  260 WRITE(6,11)
      STOP
      END
7
```

APPENDIX B

APPENDIX B

A SAMPLE SOLUTION FOR A HYPOTHETICAL COMMUNITY

Table B1. Inter-use and Intra-use Flows

Origin Use	Destination Use 1	2	3	4	5	6	7
1	1.0	1.0	1.0	4.0	3.0	6.0	0.0
2	1.3	1.3	1.3	5.2	3.9	7.8	0.0
3	1.0	3.0	0.9	5.0	6.0	7.0	0.0
4	8.0	20.0	8.5	0.0	2.0	8.0	0.0
5	6.0	24.0	8.0	1.0	0.0	7.0	0.0
6	116.0	200.0	104.4	10.0	8.8	11.2	0.0
7	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Table B2. Operating Level Differentials

Origin Use	Destination Use 1	2	3	4	5	6	7
1	0.00	0.01	0.02	0.03	0.08	0.05	0.00
2	0.01	0.00	0.01	0.02	0.07	0.04	0.00
3	0.02	0.01	0.00	0.01	0.06	0.03	0.00
4	0.03	0.02	0.01	0.00	0.02	0.02	0.00
5	0.04	0.03	0.02	0.01	-0.04	0.01	0.00
6	0.04	0.03	0.02	0.01	0.04	-0.01	0.00
7	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B3. Initial Use Allocation

		Location Number									
		1	2	3	4	5	6	7	8	9	10 (Slack)
		Location Size (Acres)									
		160	180	140	160	160	160	150	175	155	345
Use Number	Required Acreage	Acres of Use Allocated to Each Location									
1	390	95	0	35	0	0	0	0	65	0	195
2	300	0	0	0	0	50	0	0	0	100	150
3	600	50	180	0	160	55	100	55	0	0	0
4	140	0	0	100	0	0	0	40	0	0	0
5	140	0	0	0	0	40	40	0	20	40	0
6	25	0	0	5	0	15	0	0	5	0	0
7	190	15	0	0	0	0	2	55	85	15	0

Table B4. Location Use Return

Use Number	Location 1	2	3	4	5	6	7	8	9	10
	Return (Dollars per Acre)									
1	10.90	10.70	10.50	10.70	10.40	10.50	10.30	10.30	10.10	0.00
2	10.90	10.70	10.50	10.70	10.60	10.50	10.30	10.30	10.10	0.00
3	10.70	10.60	10.50	10.60	10.60	10.50	10.40	10.40	10.30	0.00
4	10.10	10.10	11.70	10.20	11.90	11.70	11.30	11.50	11.90	0.00
5	10.00	10.00	11.50	11.00	11.60	11.30	11.20	11.40	11.70	0.00
6	10.30	10.30	11.50	10.40	11.50	11.50	11.50	11.50	11.50	0.00
7	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00

Table B5. Cost of Unit Inter-location Flow

	Destination Location									
	1	2	3	4	5	6	7	8	9	10
Origin Location	Flow Cost (Dollars per Daily Trip per Annum)									
1	0.00	0.10	0.20	0.10	0.30	0.30	0.20	0.30	0.40	0.00
2	0.20	0.00	0.10	0.20	0.10	0.20	0.30	0.20	0.30	0.00
3	0.40	0.10	0.00	0.30	0.20	0.20	0.40	0.20	0.20	0.00
4	0.10	0.30	0.30	0.00	0.10	0.20	0.10	0.30	0.30	0.00
5	0.20	0.10	0.10	0.10	0.00	0.10	0.30	0.10	0.20	0.00
6	0.30	0.20	0.10	0.20	0.10	0.00	0.30	0.30	0.10	0.00
7	0.20	0.30	0.30	0.10	0.30	0.30	0.00	0.10	0.30	0.00
8	0.30	0.20	0.20	0.20	0.10	0.20	0.20	0.00	0.10	0.00
9	0.40	0.30	0.20	0.30	0.30	0.10	0.20	0.10	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table B6. Inter-location Transmission of By-products

Origin Location	Destination Location and Transmission Value															
1	2	1.0	3	0.0	4	1.0	5	0.0	6	0.0	7	0.0	8	0.0	9	0.0
2	1	1.0	3	1.0	4	0.0	5	1.0	6	0.0	7	0.0	8	0.0	9	0.0
3	1	0.0	2	1.0	4	0.0	5	0.0	6	1.0	7	0.0	8	0.0	9	0.0
4	1	1.0	2	0.0	3	0.0	5	1.0	6	0.0	7	1.0	8	0.0	9	0.0
5	1	0.0	2	1.0	3	0.0	4	1.0	6	1.0	7	0.0	8	1.0	9	0.0
6	1	0.0	2	0.0	3	1.0	4	0.0	5	1.0	7	0.0	8	0.0	9	1.0
7	1	0.0	2	0.0	3	0.0	4	1.0	5	0.0	6	0.0	8	1.0	9	0.0
8	1	0.0	2	0.0	3	0.0	4	0.0	5	1.0	6	0.0	7	1.0	9	1.0
9	1	0.0	2	0.0	3	0.0	4	0.0	5	0.0	6	1.0	7	0.0	8	1.0

Table B7. Interchange Limits (acres)

Use	1	2	3	4	5	6	7
Maximum Move	10.0	10.0	10.0	5.0	4.0	2.0	200.0
Minimum Move	2.0	2.0	2.0	1.0	0.8	0.4	0.0

Table B8. Reallocation of Uses

Use Number	Acres of Use Reallocated to Location Number								
	1	2	3	4	5	6	7	8	9
1	90	0	30	0	0	0	10	60	0
2	10	4	0	0	45	0	0	0	95
3	45	175	9	155	55	95	50	10	7
4	0	0	98	5	0	0	38	0	0
5	0	0	0	0	40	38	0	24	38
6	0	0	4	0	14	0	0	5	2

APPENDIX C

APPENDIX C

LAFAYETTE, INDIANA PIAN AREA APPLICATION

Table C1. Required Total Acreage of Each Use - Lafayette.

High density residential (max. 25 units/acre)	R_H - 1,583
Med. density residential (max. 6.5 units/acre)	R_M - 3,046
Low density residential (max 4.3 units/acre)	R_L -13,414
Industrial	I - 3,325
Industrial research	IR - 1,470
Central business district	CBD - 170
Commercial	Comm.- 1,100
Parkland	Parks - 1,880
Purdue University	PU - 2,965

Table C2. Floor Space Value of Existing Residential Structures - Lafayette (dollars per square foot)

Structure Rating		Number of Stories		
Condition	Occupancy	1	1½	2
Excellent	Single-family	15	14	13
Good	Single-family	12	11	10
Fair	Multi-family	--	10	9
Fair	Single-family	9	8	7
Poor	Multi-family	--	--	6
Poor	Single-family	5	4.5	4

Table C3. Existing Cultural Feature Value for a Given Land Use - Lafayette (dollars per acre).

	R_H	R_M	R_L	I&IR	CBD	Comm	Parks	PU
Utilities and Parking	5,625	4,875	4,500	10,000	5,000	6,000	0	0
Negative Disruption	3,000	2,000	1,500	3,000	2,000	2,000	0	0
Structures	(See Table C2)			65,000	215,000	105,000	1,000*	500,000

*Increased to $50,000 for Happy Hollow and Columbia Parks

Table C4. Natural Feature Value for a Given Land Use - Lafayette (dollars per acre).

	R_H	R_M	R_L	I&IR	CBD	Comm	Parks	PU
Cover	0	3,000	3,000	0	0	0	5,000	0
Topography (Low)	1,000	500	0	0	0	0	-2,500	0
Topography (Med.)	500	1,000	1,500	-500	-1,000	-500	2,500	0
Topography (High)	0	1,500	3,000	-5,000	-10,000	-1,500	5,000	0
Poor Drainage	-1,500	-1,500	-1,000	-1,500	- 1,500	-1,500	0	0

Table C5. Inter-use Trip Generation Rates per Acre of Origin Use - Lafayette.

Origin Uses	Destination Uses								
	R_H	R_M	R_L	I	IR	CBD	Comm	Parks	PU
R_H	-	-	-	2.38	1.16	3.40	9.22	0.35	5.10
R_M	-	-	-	1.15	0.56	1.64	4.41	0.15	2.47
R_L	-	-	-	0.68	0.33	0.97	2.65	0.10	1.46
I	1.08	1.02	2.57	-	-	0.20	0.30	-	-
IR	1.29	1.21	2.97	-	-	0.20	0.20	-	0.20
CBD	31.10	29.20	72.90	3.90	1.73	-	6.47	-	2.40
Comm	13.40	12.70	32.20	0.60	0.27	1.00	-	-	-
Parks	0.35	0.28	0.81	-	-	-	-	-	-
PU	86.00	81.50	207.60	-	3.27	5.00	-	-	-

Table C6. Assumed Average Overall Speed by Facility Type - Lafayette

Facility	Average Speed (Miles per Hour)
Local Street	15
Arterials	25
Parkway	40
Interstate-65	50

Table C7. Incompatibility Costs for Proximate Uses - Lafayette.

By-product Recipient Use	By-product Source Use									
	R_H	R_M	R_L	I	IR	CBD	Comm	Parks	PU	Vacant
	Cost (dollars)									
R_H	0	0	0	10,000	0	9,000	4,500	0	0	0
R_M	600	0	0	8,000	0	6,000	3,000	0	0	0
R_L	1,500	750	0	8,000	1,500	6,000	3,000	1,000	0	0
I	0	0	0	0	0	0	0	0	0	0
IR	0	0	0	4,000	0	2,000	1,000	0	0	0
CBD	0	0	0	1,000	0	0	0	0	0	0
Comm	0	0	0	3,000	0	0	0	0	0	0
Parks	0	0	0	10,000	0	0	0	0	0	0
PU	0	0	0	0	0	5,000	0	0	0	0
Vacant	0	0	0	0	0	0	0	0	0	0

Table C8. Transmission Values of By-products through Barriers - Lafayette

Barrier	By-product Transmission Value
None (adjacent)	1.0
Railroad	0.9
Major Street	0.8
Lake	0.7
Ravine	0.7
Hill	0.5
River	0.5
Interstate-65	0.5
Intervening Use (non-adjacent)	0.0

Table C9. Interchange Limits - Lafayette (acres).

	Type of Use									
	R_H	R_M	R_L	I	IR	CBD	Comm	Parks	PU	Vacant
Maximum	10	20	40	40	40	5	5	20	0	300
Minimum	2	4	8	8	8	1	1	4	0	0

Table C10. Locations by Districts - Lafayette

District	Locations
1	1 2 3 4 18 19 20 21 35 36 37 38 52 53 54 55 69 70 71
2	5 6 7 8 9 22 23 24 25 39 40 41 42 43 56 57 58 59
3	10 11 12 13 26 27 60
4	16 17 32 33 34 48 49 50 51 64 65 66 67 68 82 83 84 85 98 99
5	86 87 88 89 103 104 105 106 107 120 121 122 123 124 140 141
6	108 109 125 126 127 142 143 144 158 159 160 161
7	78 95 112 113 114 115 116 117 128 129 130 131 132 133 134 152
8	100 101 102 118 119 135 136
9	137 138 139 154 155 156 157 171 172 173 174 175
10	145 146 147 162 163 178 179
11	148 149 150 151 164 165 166 167 180 181 182 183 184
12	153 169 170 185 186 187 203 204
13	176 188 189 190 191 192
14	225 239 240 241 242 256 257 258 259 273 274 275 276
15	194 210 211 226 227 228 229 243 244 245 260 261 277 278
16	195 196 197 198 212 213 214 215 230 231 232 233
17	199 200 201 202 216 217 218 219 234 235 236
18	246 247 262 263 264 265 279 280 281 282 283
19	248 249 250 251 252 266 267 268 269 270 284 285 286 287 288
20	220 221 237 238 253 254 255 271 272 289
21	72 73 74 75 76 90 91 92 93 110

Table C11. Initial Allocation of Uses (Sample) - Lafayette

Location		Acreage of Use Allocated								
No.	Size	1	2	3	4	5	6	7	8	9
46				Flood Plain and/or River						
47				Flood Plain and/or River						
48	108	0	0	0	0	0	0	0	0	0
49	117	0	0	117	0	0	0	0	0	0
50	195	0	0	0	0	0	0	0	0	0
51	176	0	0	0	0	0	0	0	0	0
52	174	0	0	0	0	60	0	35	0	0
53	145	0	5	140	0	0	0	0	0	0
54	242	0	14	222	0	6	0	0	0	0
55	100	0	0	50	9	40	0	1	0	0
56	130	0	0	0	0	130	0	0	0	0
57	155	0	0	145	10	0	0	0	0	0
58	320	0	0	320	0	0	0	0	0	0
59	130	0	0	130	0	0	0	0	0	0
60	80	0	0	68	0	0	0	2	10	0
61				Flood Plain and/or River						
62				Flood Plain and/or River						
63				Flood Plain and/or River						
64	135	0	0	0	0	0	0	0	0	0
65	145	0	0	91	3	0	0	0	0	0
66	110	0	0	40	0	0	0	0	0	0
67	110	0	0	0	0	0	0	0	0	0
68	71	0	0	0	0	0	0	0	0	0
69	101	0	5	0	5	91	0	0	0	0
70	193	0	0	193	0	0	0	0	0	0
71	130	0	0	130	0	0	0	0	0	0
72	217	0	0	216	0	0	0	1	0	0
73	110	0	0	0	0	60	0	50	0	0
74	213	17	0	179	0	3	0	13	0	0
75	170	17	0	145	0	0	0	8	0	0
76	183	5	0	178	0	0	0	0	0	0
77				Flood Plain and/or River						
78	227	0	0	85	14	0	0	0	0	0
79				Flood Plain and/or River						
80				Flood Plain and/or River						
81				Flood Plain and/or River						
82	85	0	0	10	0	0	0	0	0	0
83	200	0	0	0	78	0	0	0	0	0
84	120	0	0	0	0	0	0	0	0	0
85	311	0	0	15	0	0	0	0	0	0
86	209	0	0	0	0	209	0	0	0	0
87	180	0	0	40	0	140	0	0	0	0
88	108	0	0	108	0	0	0	0	0	0
89	161	0	0	161	0	0	0	0	0	0
90	160	0	0	0	0	0	0	0	0	160
91	130	0	40	75	0	0	0	15	0	0

Table C12. Reallocation of Uses (Sample) - Lafayette

Location		Acreage of Use Allocated								
No.	Size	1	2	3	4	5	6	7	8	9
46				Flood Plain and/or River						
47				Flood Plain and/or River						
48	108	0	0	0	0	0	0	0	0	0
49	117	0	0	97	0	0	0	0	0	0
50	195	0	0	0	0	0	0	0	0	0
51	176	0	0	0	0	0	0	0	0	0
52	174	0	0	0	0	40	0	32	0	0
53	145	0	0	120	0	0	0	0	0	0
54	242	0	4	202	0	0	0	0	0	0
55	100	0	0	30	0	20	0	0	0	0
56	130	0	0	0	0	110	0	0	0	0
57	155	0	0	125	0	0	0	0	0	0
58	320	0	0	300	0	0	0	0	0	0
59	180	0	0	160	0	0	0	0	0	0
60	80	0	0	48	0	0	0	0	0	0
61				Flood Plain and/or River						
62				Flood Plain and/or River						
63				Flood Plain and/or River						
64	135	0	0	0	0	0	0	0	0	0
65	145	0	0	71	0	0	0	0	0	0
66	116	0	0	20	0	0	0	0	0	0
67	116	0	0	0	0	0	0	0	0	0
68	71	0	0	0	0	0	0	0	0	0
69	101	0	0	0	0	71	0	0	0	0
70	193	0	0	173	0	0	0	0	0	0
71	130	0	0	110	0	0	0	0	0	0
72	217	0	20	197	0	0	0	0	0	0
73	110	0	20	3	0	60	0	27	0	0
74	213	12	20	165	0	0	0	12	0	0
75	178	12	20	142	0	0	0	4	0	0
76	133	0	20	113	0	0	0	0	0	0
77				Flood Plain and/or River						
78	227	0	0	9	0	0	0	0	0	0
79				Flood Plain and/or River						
80				Flood Plain and/or River						
81				Flood Plain and/or River						
82	85	0	0	0	0	0	0	0	0	0
83	200	0	0	0	58	0	0	0	0	0
84	120	0	0	0	0	0	0	0	0	0
85	311	0	0	0	0	0	0	0	0	0
86	209	0	0	20	0	139	0	0	0	0
87	180	0	0	60	0	120	0	0	0	0
88	108	0	0	108	0	0	0	0	0	0
89	161	0	0	161	0	0	0	0	0	0
90	160	0	0	0	0	0	0	0	0	160
91	130	0	60	60	0	0	0	10	0	0

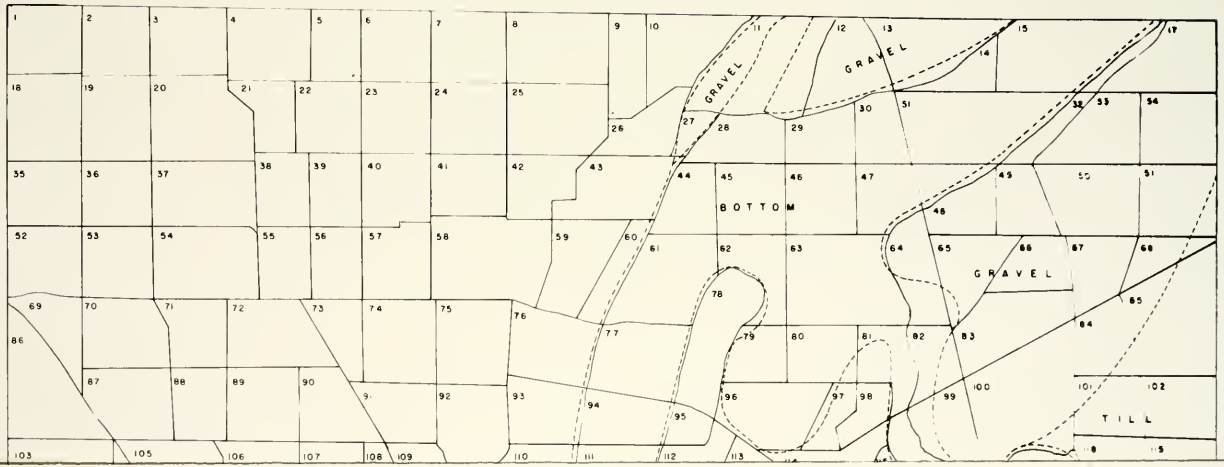

FIGURE C-1. LAFAYETTE, INDIANA AREA PLAN LOCATIONS

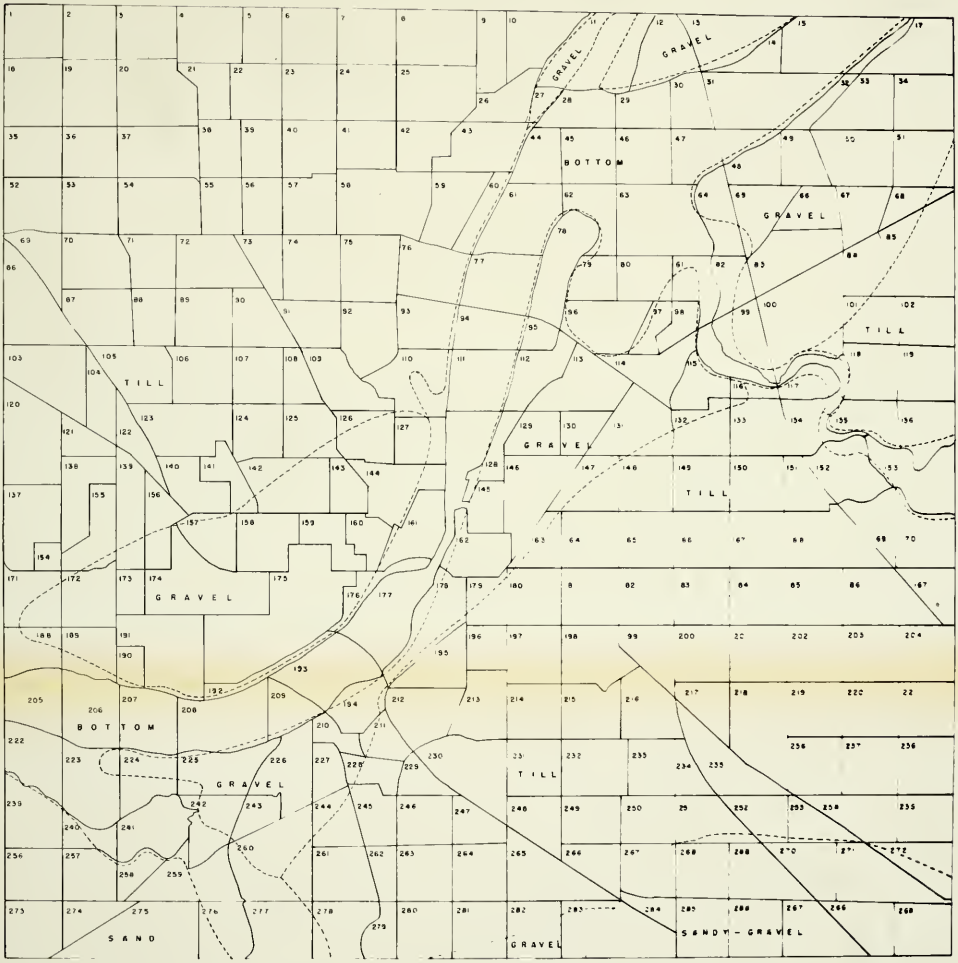

FIGURE C-1. LAFAYETTE, INDIANA AREA PLAN LOCATIONS

FIGURE C-2. LAFAYETTE, INDIANA AREA PLAN NETWORK

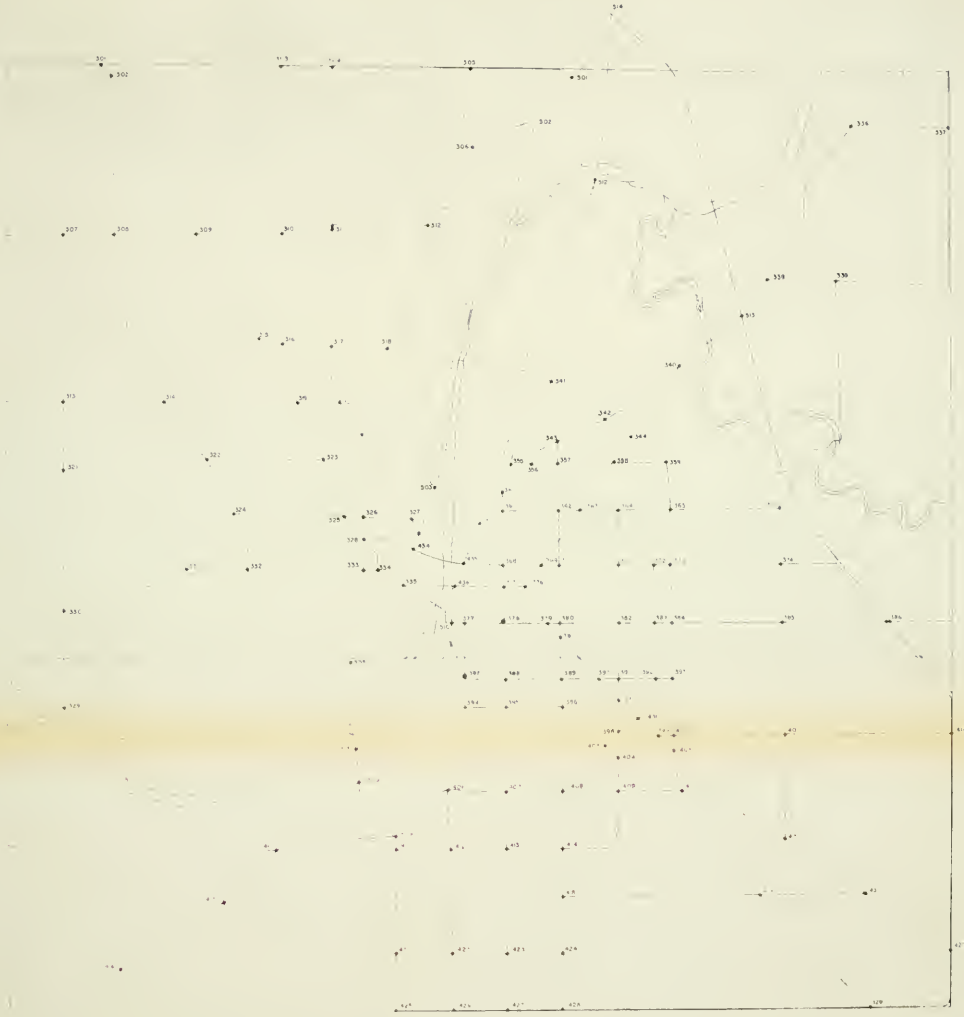

FIGURE C-2 LAFAYETTE, INDIANA AREA PLAN NETWORK

Location Number _____

Photo Scale 1" = _____

Location Area _____sq. in. _____sq. ft. _____acres

Vacant Area _____sq. in. _____sq. ft. _____acres

Vacant Area w/Cover _____sq. in. _____sq. ft. _____acres

Flood Plain _____sq. in. _____sq. ft. _____acres

Non-Residential _____sq. in. _____sq. ft. _____acres

Commercial	_____	_____	_____
Industrial	_____	_____	_____
Ind. Res.	_____	_____	_____
Public	_____	_____	_____
Parks	_____	_____	_____
Purdue	_____	_____	_____
Residential	_____	_____	_____
High Density	_____	_____	_____
Med. Density	_____	_____	_____
Low Density	_____	_____	_____

Roof Area Sample:

House 1 _____ x _____ = _____
House 2 _____ x _____ = _____
House 3 _____ x _____ = _____
House 4 _____ x _____ = _____
Total _____

Average _____
No. Houses _____
No. Storys _____
Condition _____
Block Area (acres) _____

Slope Rating _____ Soil Rating _____

Transmission Barriers (Direction and Type)

_____ _____

Figure C3. Worksheet: - Airphoto Land Use Analysis and Rating by Location

VITA

VITA

Wilfrid Donald Stewart was born on December 26, 1938 in Rivers, Manitoba, Canada. His primary education occurred mainly there, but he was graduated from Lord Byng High School in Vancouver, British Columbia.

He received the Bachelor of Applied Science in Civil Engineering Degree in 1959 from the University of British Columbia, and in 1960, a Diploma in Business Administration from the University of Western Ontario. In 1964 he received the Master of Science in Civil Engineering from Queen's University, Kingston, Ontario, Canada.

From 1960 to 1961 he was employed as a Municipal Fire Protection Engineer for Canadian Underwriter's Association. From 1961 to 1962 he was a Graduate Assistant in the Civil Engineering Department at Queen's University, and from 1962 to 1965 a lecturer at Royal Military College, Kingston.

From 1965 to September, 1967 he was a full time student at Purdue University. Since then he has been an Assistant Professor in Civil Engineering at the University of Saskatchewan, Saskatoon, Canada.

He is a Canadian citizen.